YROTATE-IT-RX62T

Low Cost Motor Control Kit based on RX62T

UM-YROTATE-IT-RX62T
Rev.1.00
Jan 15, 2014

Introduction

The Renesas Motor Control Kit, YROTATE-IT-RX62T, is based on the RX62T device from the powerful 32-bit RX microcontroller family.

The kit enables engineers to easily test and evaluate the performance of the RX62T in a laboratory environment when driving any 3-phase Permanent Magnet Synchronous Motor (e.g. AC Brushless Motor) using an advanced sensorless Field Oriented Control algorithm. Typical applications for this type of solution are compressors, air conditioning, fans, air extractors, pumps and industrial drives.

The phase current measurement is done via three shunts which offers a low cost solution, avoiding the need for an expensive current sensor. A single shunt current reading method is also available.

The powerful user-friendly PC Graphical User Interface (GUI) gives real time access to key motor performance parameters and provides a unique motor auto-tuning facility.

The hardware is designed for easy access to key system test points and for the ability to hook up to an RX62T debugger. Although the board is normally powered directly from the USB port of a Host PC, connectors are provided to utilise external power supplies where required.

The YROTATE-IT-RX62T is an ideal tool to check out all the key performance parameters of your selected motor, before embarking on a final end application system design.

Target Device: RX62T/63T Microcontroller Series

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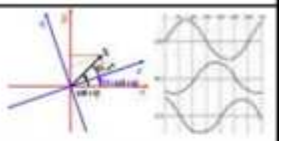
1. Key features

Motor Type	Brushless AC (e.g. Permanent Magnet AC)
Control Method	Sinusoidal waveform control, Field Oriented Control 
Current measurement	Sensorless using three Shunts
MCU type	RX62T (32-bit, 165DMIPS)
Flash usage RAM usage	9KB for motor control algorithm 2.5KB RAM
FOC algo performance	30µs with CPU at 100MHz
Switching Frequency Sampling Frequency	Up to 50KHz Up to 25KHz
Communication	USB connection: PC GUI interface Tool: E1 for debug & development

2. Hardware overview

The Motor Control kit is a single board inverter, based on the new RX series microcontroller RX62T. The hardware includes a low-voltage MOSFETs power stage, and a communication stage.

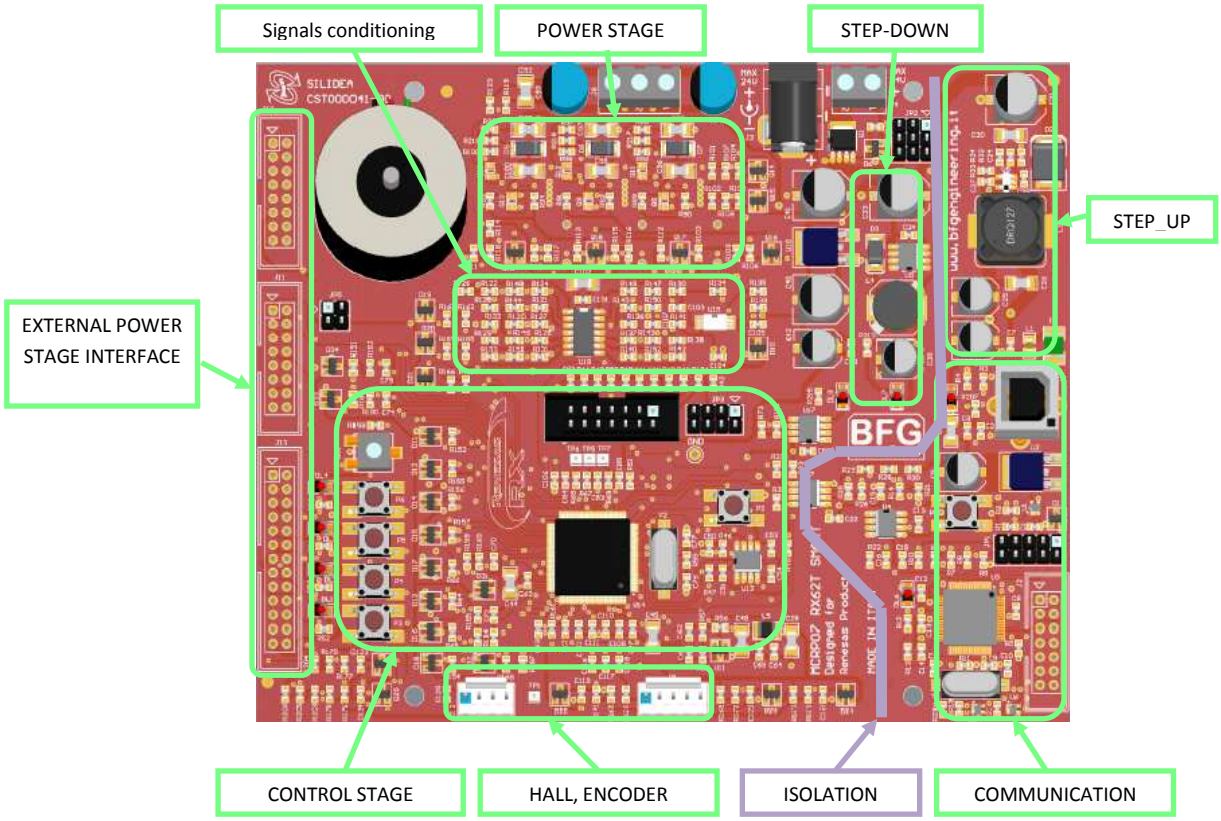
The ordering part name of the kit is: YROTATE-IT-RX62T. The latest updates of the kit material are available on the webpage: http://tinyurl.com/YROTATE-IT-RX62T

To obtain the maximum flexibility, the reference board includes:

- A complete 3-phase inverter on-board with a low voltage motor, so it becomes easy to test the powerful sensorless algorithm on the RX62T
- USB communication with the PC via a H8S2212 microcontroller
- Connectors for hall sensors and encoder connections
- Compatibility with the existing Motor Control Reference Platforms MCRP05/06 power stage available at Renesas.

To achieve these aims, an independent communication stage was implemented, based on the Renesas microcontroller H8S2212, which performs the USB to serial conversion.

The two serial lines RX and TX are fully insulated



This stage uses the PC USB power lines as power supply.

Furthermore, the possibility to supply all the board using the PC USB port was added, realizing a step-up converter to obtain the inverter V_{BUS} necessary for the motor; obviously, if this feature is used, the system is no more insulated from the PC.

If external power supply is used for the inverter, the logic power supply is obtained through a step-down converter, in order to reduce heating and power consumption.

Please refer to the electrical drawings or schematics to get the hardware implementation in more details.

3. Power supply selection

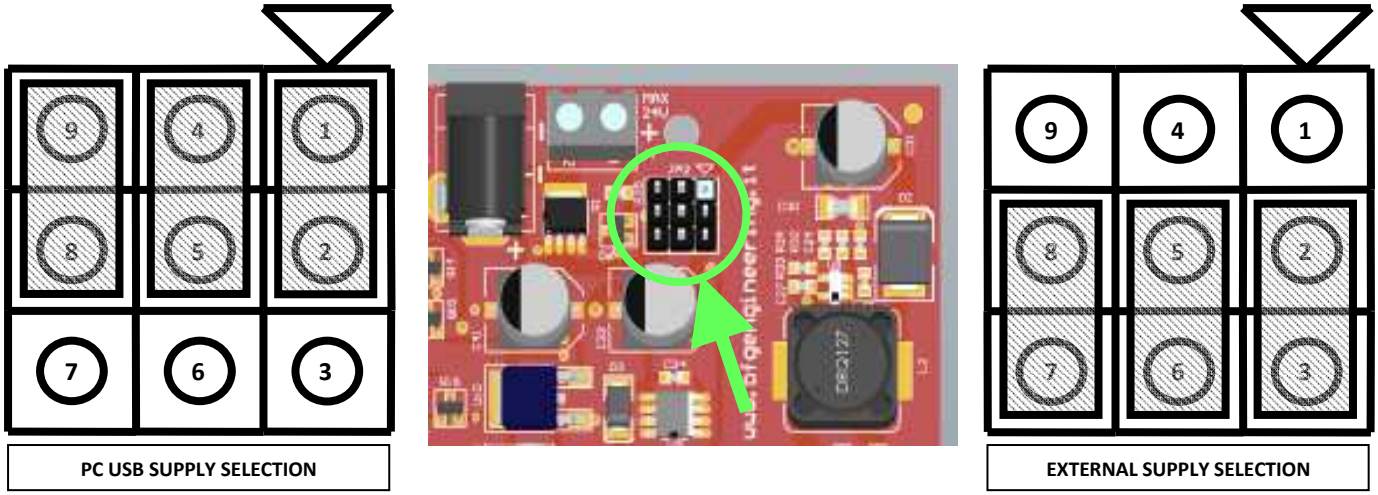
As stated before, there are two ways to supply power to the board.

One possibility is to use directly the PC USB supply, and in this case the current you can give to the motor is limited by the USB possibilities. A dual power USB cable is recommended to give enough power to the board.

The second possibility is to use an external voltage DC source to supply the board.

The recommended voltage values are between $12V_{DC}$ and $24V_{DC}$. In this case the communication stage is insulated from the inverter.

The selection between the two possibilities is made through three jumpers in the J2 connector, as described in the following figure.



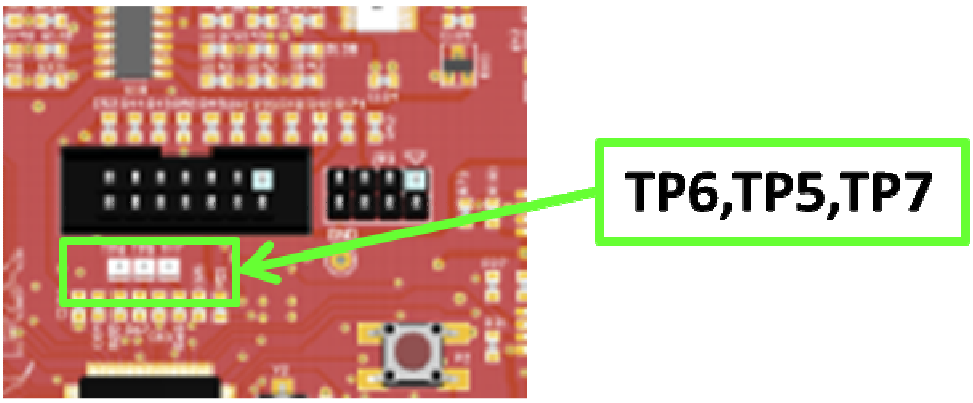
The first jumper configuration connects the USB ground to the inverter ground, the USB 5Vdc to the logic +5Vdc and the output of the step-up converter (around 13Vdc) to the inverter DC link.

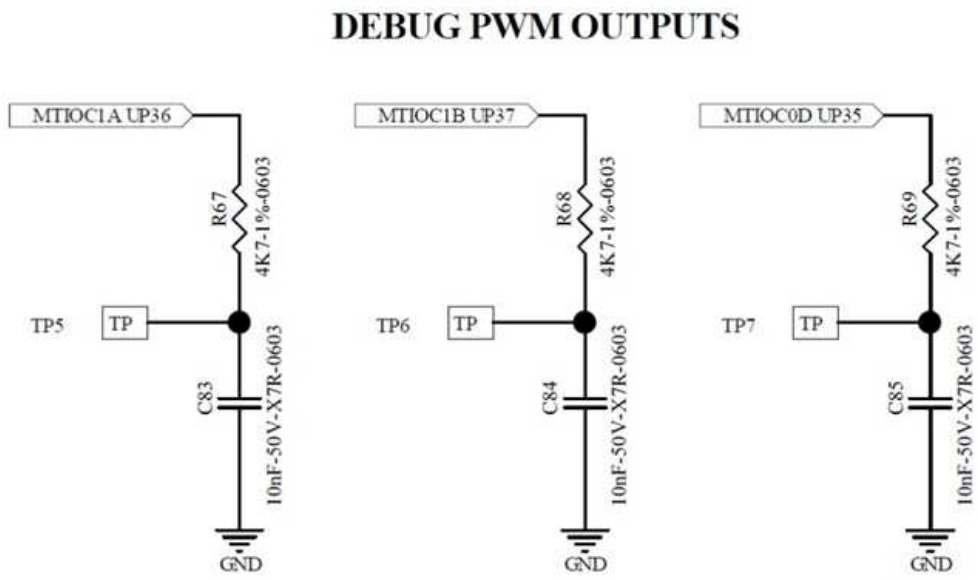
The second jumper configuration connects the external power supply ground to the inverter ground, the output of the step-down converter (+5Vdc) to the logic +5Vdc and the external +Vdc (from 12 to 24 Vdc) to the inverter DC link.

4. Test points for debugging

Several specific test points are available on the board to visualize with the oscilloscope the behavior of some internal analog signals. it is very useful during the tuning process for adapting the software to a new motor to use the test points.

There are specific 3 PWM debug test points; TP5, TP6 & TP7 as shown below.

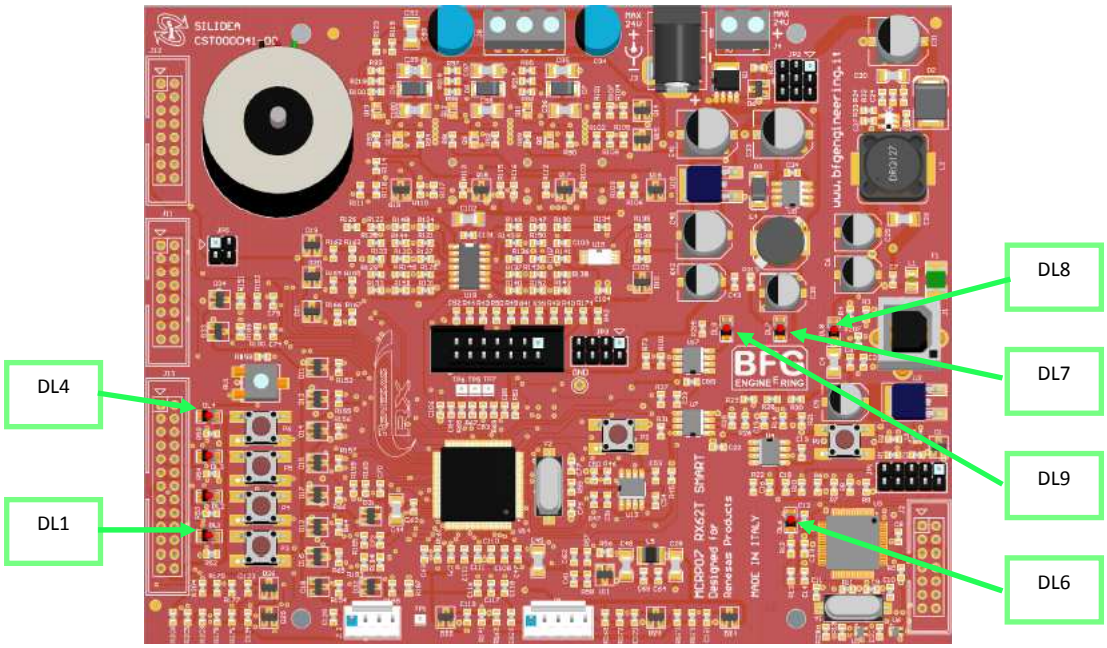




5. LEDs function description

Three LEDs available on the board are directly connected to the hardware and allows the user to understand the status of the supply of the board. Please refer to the LED map for the following indications:

- DL8 is connected to the USB supply, so it indicates that the USB port is supplied (and, by consequence, all the communication section).
- DL7 is connected to the step-down converter output, and it is on only if an external power supply is connected.
- DL9 is connected to the logic supply, so it indicates that the control section is supplied.



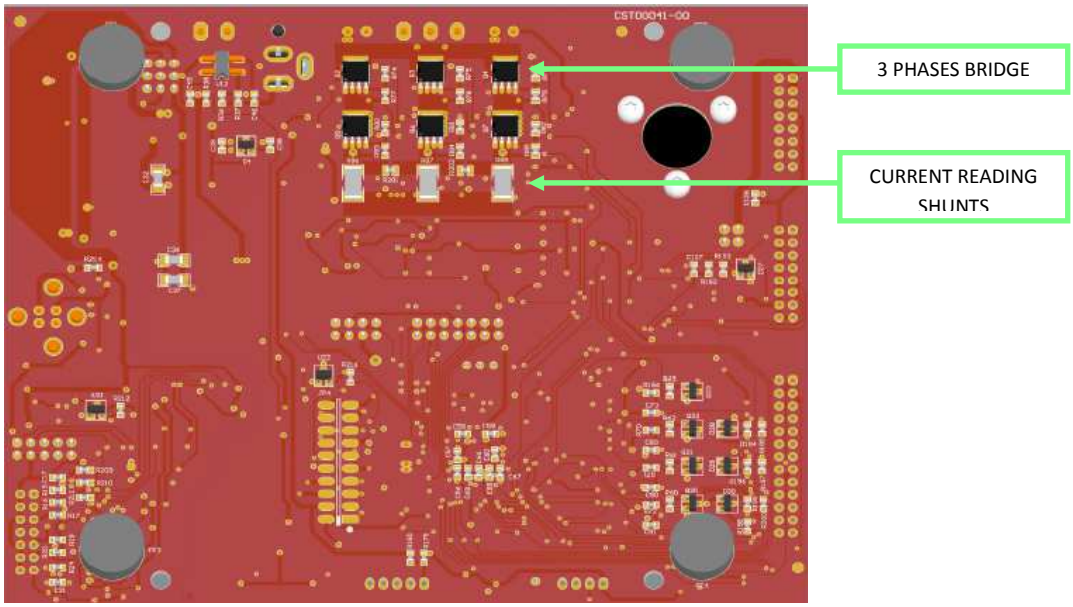
The other LEDs in the board are driven via software, in particular:

- DL6 is blinking if there is a communication between the PC and the board.
- DL1 is blinking if the control section microcontroller (RX62T) is running normally.
- DL4 is quickly blinking if an alarm has been detected.

6. Internal power stage brief description

The power stage is a complete 3-phase bridge composed with discrete low voltage power MOSFETs, mounted on the bottom side of the board. The MOSFETs are the Renesas **RJK0654DPB** n-channel power MOSFETs (please refer to the data-sheet for the characteristics).

On the upper side of the board is mounted the MOSFETs driving circuit, composed with discrete elements (refer to the electric drawings).



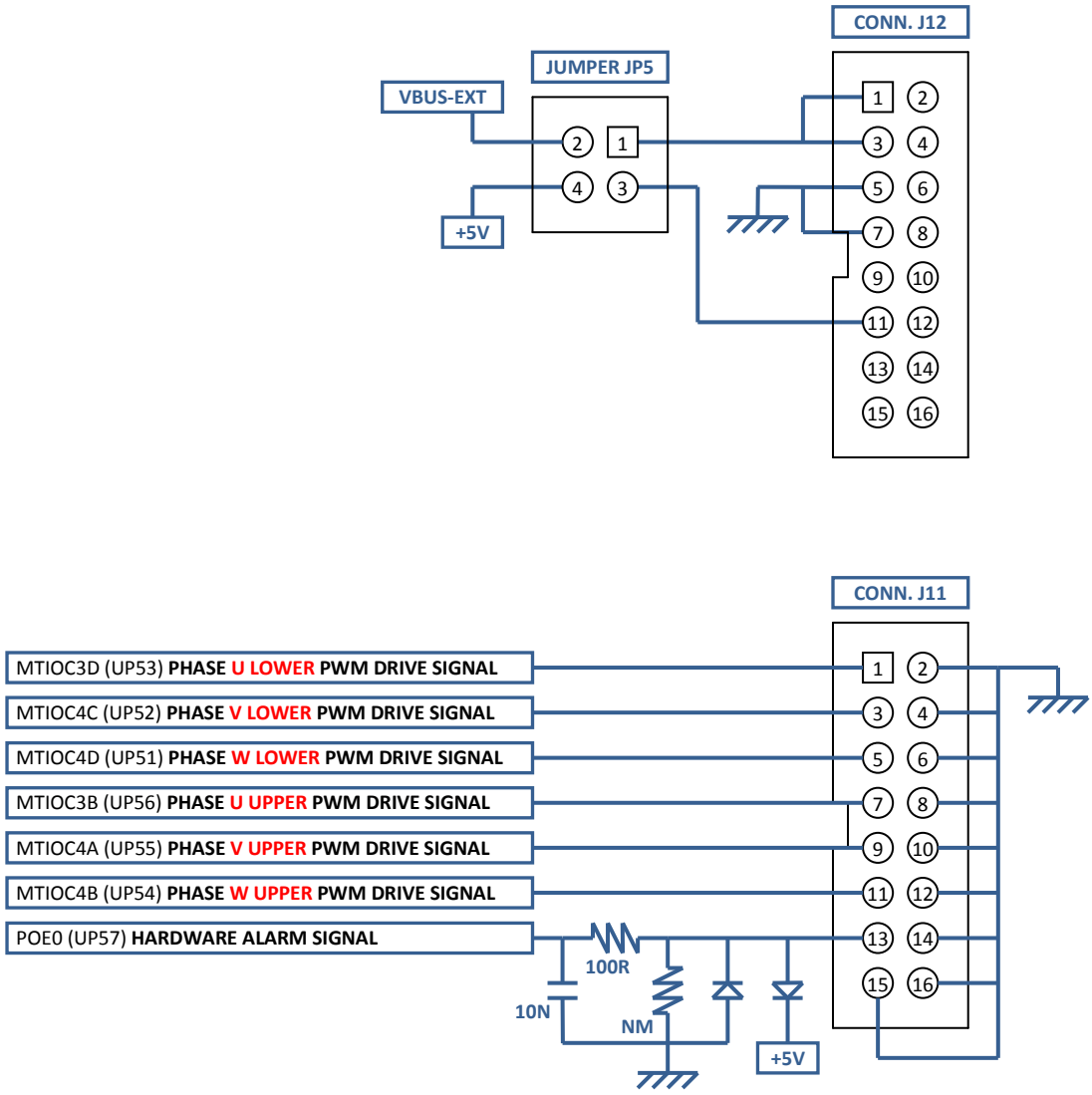
The current reading shunts are also in the bottom side of the board, while the signal conditioning circuit is in the upper side.

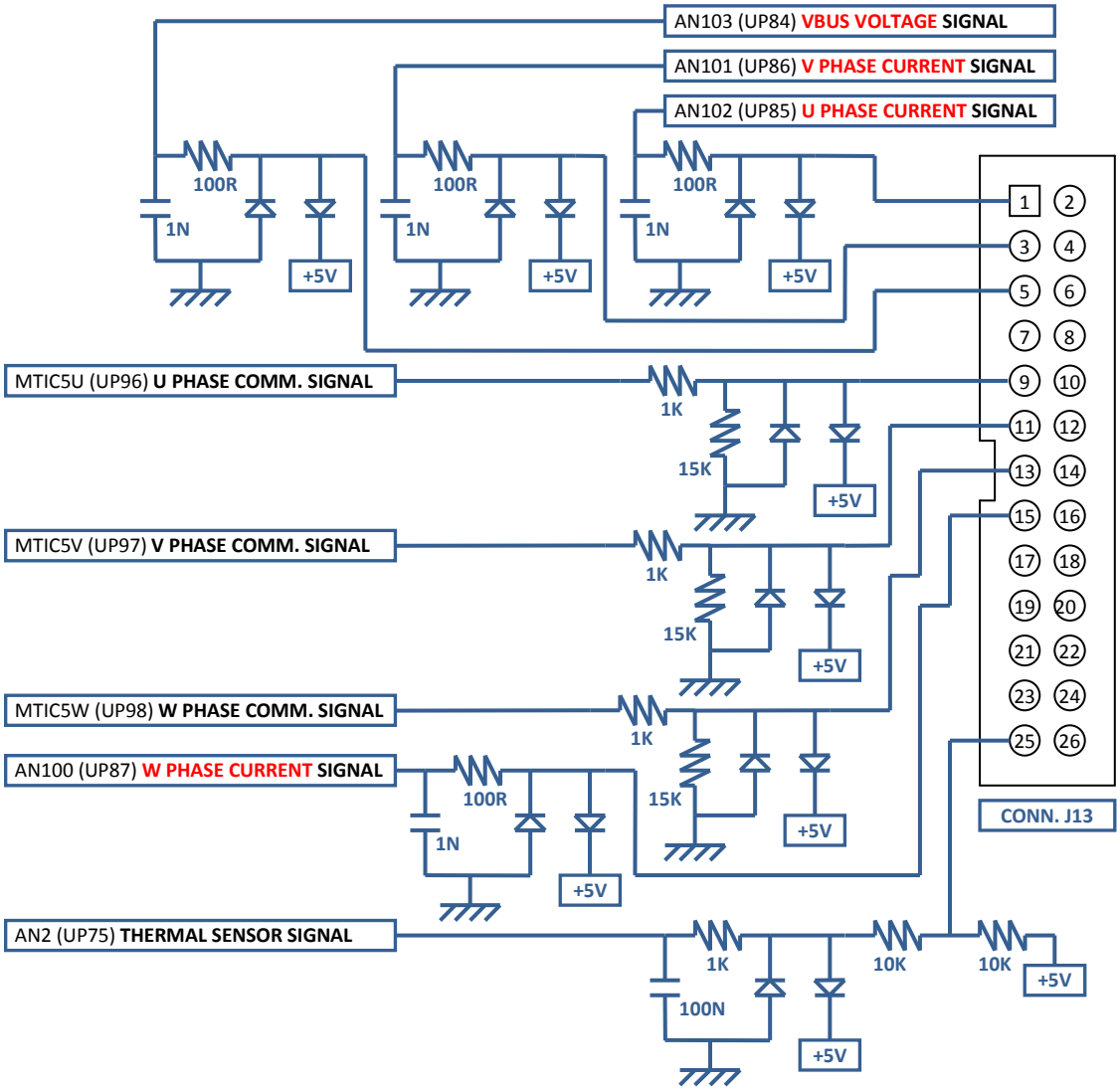
The inverter has the classical schema with the three shunts on the lower arms:

7. Interface with an external power stage

Since internal power stage allows only the management of small motors, an interface with an external power stage was added to the PCB. This was made easy due to the presence in the microcontroller of several timer sections that make it possible to manage up to two 3-phase Brushless AC motors at the same time.

Please find below the schematics of the connectors present in the board, used for connecting an external power stage.


CONN. J12
JUMPER JP5
VBUS-EXT
+5V
CONN. J11
MTIOC3D (UP53) PHASE U LOWER PWM DRIVE SIGNAL
MTIOC4C (UP52) PHASE V LOWER PWM DRIVE SIGNAL
MTIOC4D (UP51) PHASE W LOWER PWM DRIVE SIGNAL
MTIOC3B (UP56) PHASE U UPPER PWM DRIVE SIGNAL
MTIOC4A (UP55) PHASE V UPPER PWM DRIVE SIGNAL
MTIOC4B (UP54) PHASE W UPPER PWM DRIVE SIGNAL
POE0 (UP57) HARDWARE ALARM SIGNAL
100R
10N
NM
+5V



The interface between the board and an external power stage is organized as follows:

a) A 16 pins connector (J11) is used for the PWM drive signals; the signals are directly connected to the microcontroller output pins, and there is no pull-up or pull-down resistor connected, so the polarization has to be done in the power stage (note that in case of alarm, the microcontroller output pins can be placed in high impedance state, so the external polarization is necessary); these output commands are logic level signals, with limited current output capability, so an external driver is probably required. A further line is connected to the microcontroller: it is the external alarm signal, connected to the POE input pin; this pin is not polarized, so if the POE is enabled and the input is left unconnected, undesired alarms can occur. All the free pins of the connector are connected to the board ground to minimize the cross talking of the lines if a flat cable is used.

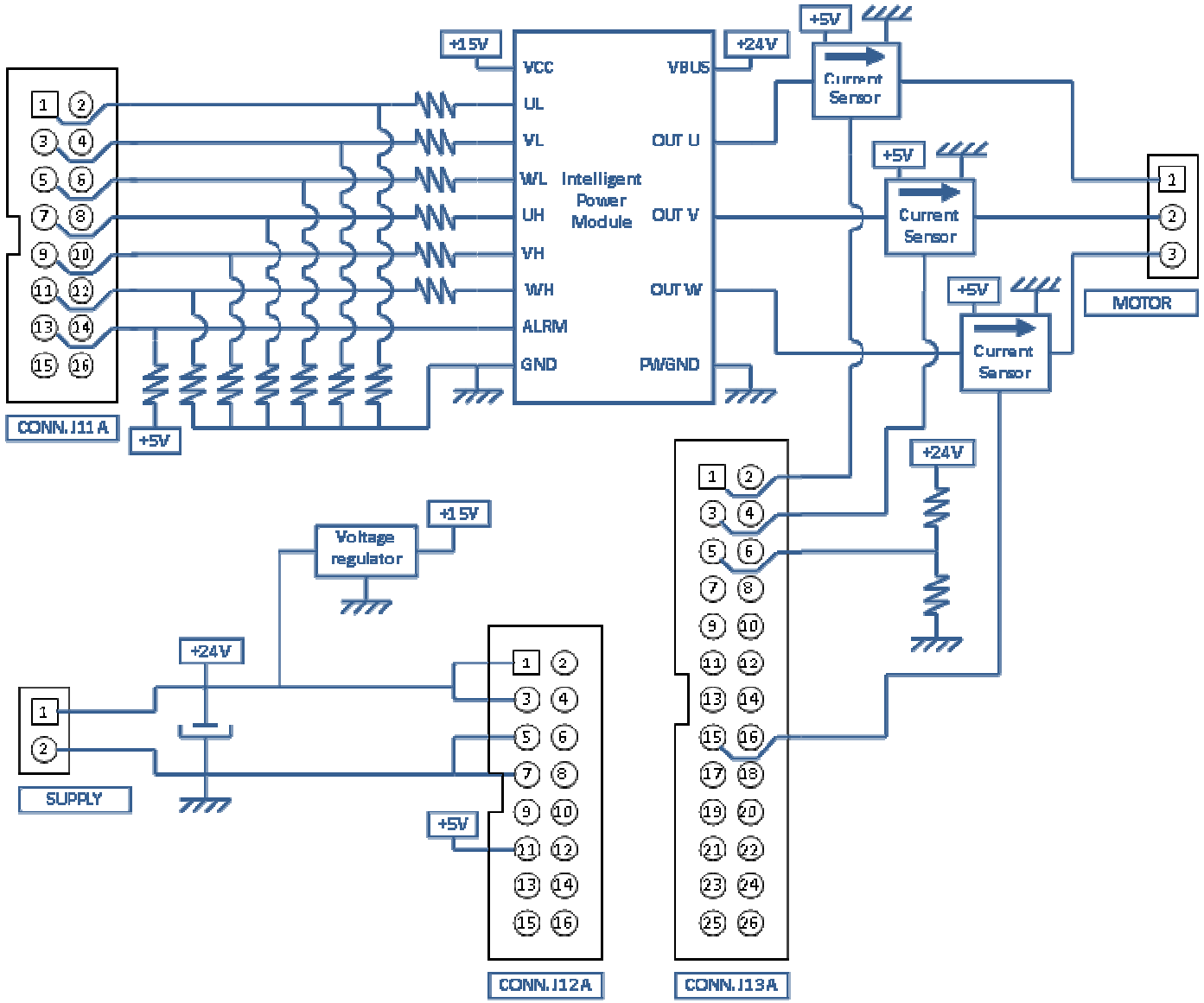
b) A 26 pins connector (J13) is used to collect some signals from the power stage, in particular the current readings and the DC link voltage reading; those signals are clamped and weakly filtered, then directly connected to the A/D converter input pins of the microcontroller, so the external power stage has to take care of the gain and the offset of these signals. An input is dedicated also to a thermal sensor, and a pull-up resistor is present. Three further signals are managed: they are the commutation signals from the output phases, useful if the hardware compensation of dead-times facility of the MTU is used; those signals are

clamped with a diode directly connected with the microcontroller power supply, so a suitable series resistance is needed in the power stage to avoid damages to the board.

c) A further connector (J12) can be used to supply the board from the power stage or vice-versa (making a short circuit between the pins 1 and 2 of the jumper JP5); also the board 5V can be made available to the power board (making a short circuit between the pins 3 and 4 of JP5), but not vice-versa, because they are directly connected to the step-down switching supply of the board. The ground connection is always on, and it represents the reference for all the interface signals.

In the next figure a simple example regarding how the power board has to be arranged is presented: the power supply comes from the supply connector, and the supply for power module is derived from it. The external supply is also used to supply the microcontroller board through the connector J12A (and the jumper JP5 in microcontroller board); the 5V supply for current sensors and for the signal polarization is derived from the microcontroller board, through J12A (and JP5). The PWM drive signals are taken from J11A, while the current sensing signals and the bus voltage measurement are brought to J13A (the phase commutation signals and the temperature sensing signal are not reported for sake of simplicity).

Please refer to the complete schematics for further details.


+15V
VCC
UL
VL
WL
UH
VH
WH
ALRM
GND
Intelligent Power Module
VBUS
OUT U
OUT V
OUT W
PWGND
+24V
+5V
Current Sensor
MOTOR
CONN.J11A
Voltage regulator
SUPPLY
CONN.J12A
CONN.J13A

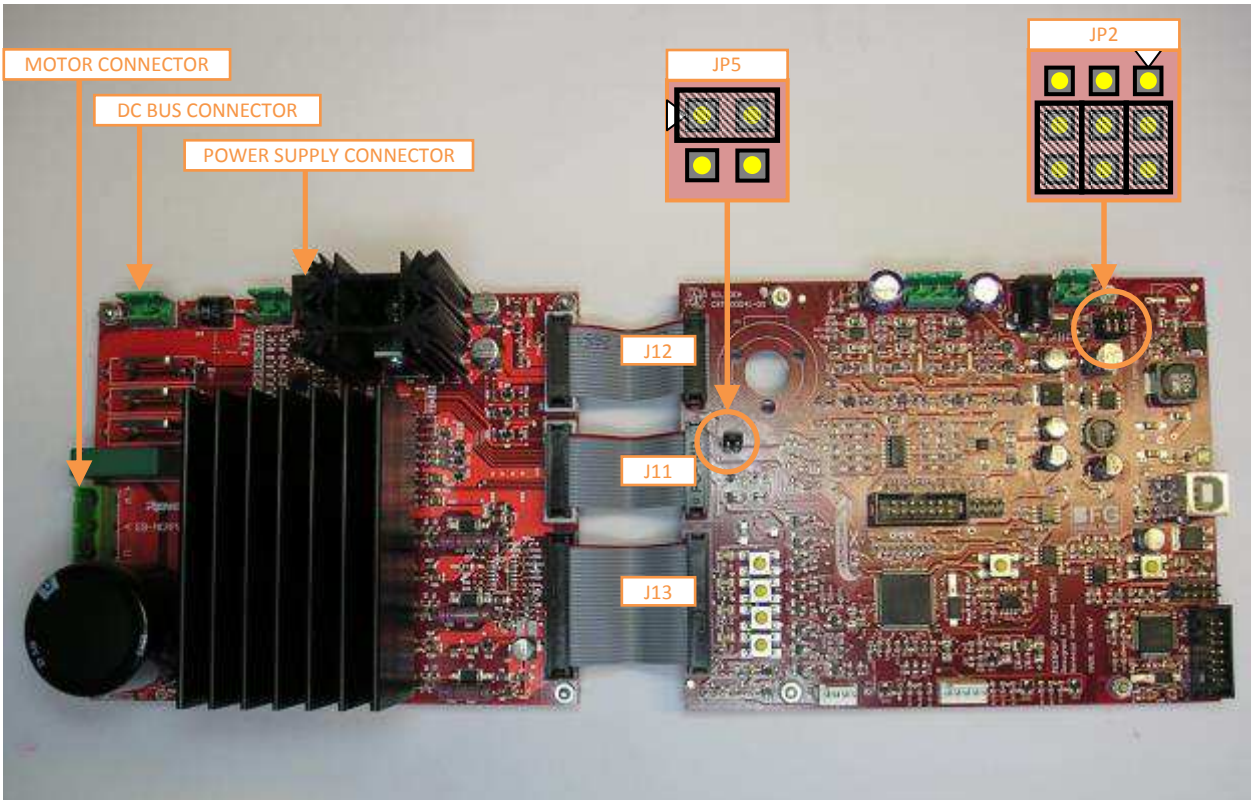
8. Connection with a 1.5KW external power stage

The interface for an external power supply was designed to be compatible with the power stages of previous Renesas motor control platforms MCRP05/06.

So it becomes possible to use the same power stage and connect any Motor Control board using RX62T, RL78/G14 or RX220 microcontroller families.

The schematics of a 1.5KW power stage are included into the documentation on the CD-ROM delivered with the Kit.

Please find below the details to connect the power stage to the RX62T motor control kit.



The power supply of $24V_{DC}$ is delivered by the 1.5KW power board (on the left hand side). It's directly connected to the RX62T control board thanks to the Jumper **JP5** (on the right hand side).

The pin 1 and 2 of the jumper **JP5** are short-circuited, while the pin 3 and 4 are left open.

In the microcontroller board, the supply configuration jumper **JP2** is configured in order to select the external supply (not the USB one).

In the power stage board, a DC bus connector allows the user to provide a higher external DC voltage; in such way high voltage motors can be managed.

9. Control microcontroller overview

The RX62T/63T Group is a set of microcontrollers featuring the high-speed, high-performance RX CPU as the 100MHz processor core.

Each basic instruction of the processor is executable in one cycle of the system clock. Calculation functionality is enhanced by the inclusion of a single-precision floating-point calculation unit as well as a 32-bit multiplier and divider. Additionally, code efficiency is improved by instructions with lengths that are variable in byte units to cover an enhanced range of addressing modes.

A multi-functional timer pulse unit 3 (for motor control), general PWM timer, compare match timers, watchdog timer, independent watchdog timer, serial communications interfaces, I2C bus interfaces, CAN module, serial peripheral interface, LIN module, 12-bit A/D converters with three-channel simultaneous sampling function, and 10-bit A/D converter are incorporated as peripheral functions which are essential to motor control devices. In addition, the 12-bit A/D converters include a window comparator and programmable gain amplifier for additional functionality.

Please find below the summary of the RX62T features:

RX600 CPU

- High-speed: 100MHz clock
- High performance: 1.65MIPS/MHz
- Low current consumption: only 50mA @ 100MHz
- Single-precision floating point unit FPU, barrel shifter, MAC, RMPA
- 256kB Flash/16kB RAM to 64kB Flash/8kB RAM
- Zero wait access to Flash memory
- 64pin – 112pin package options

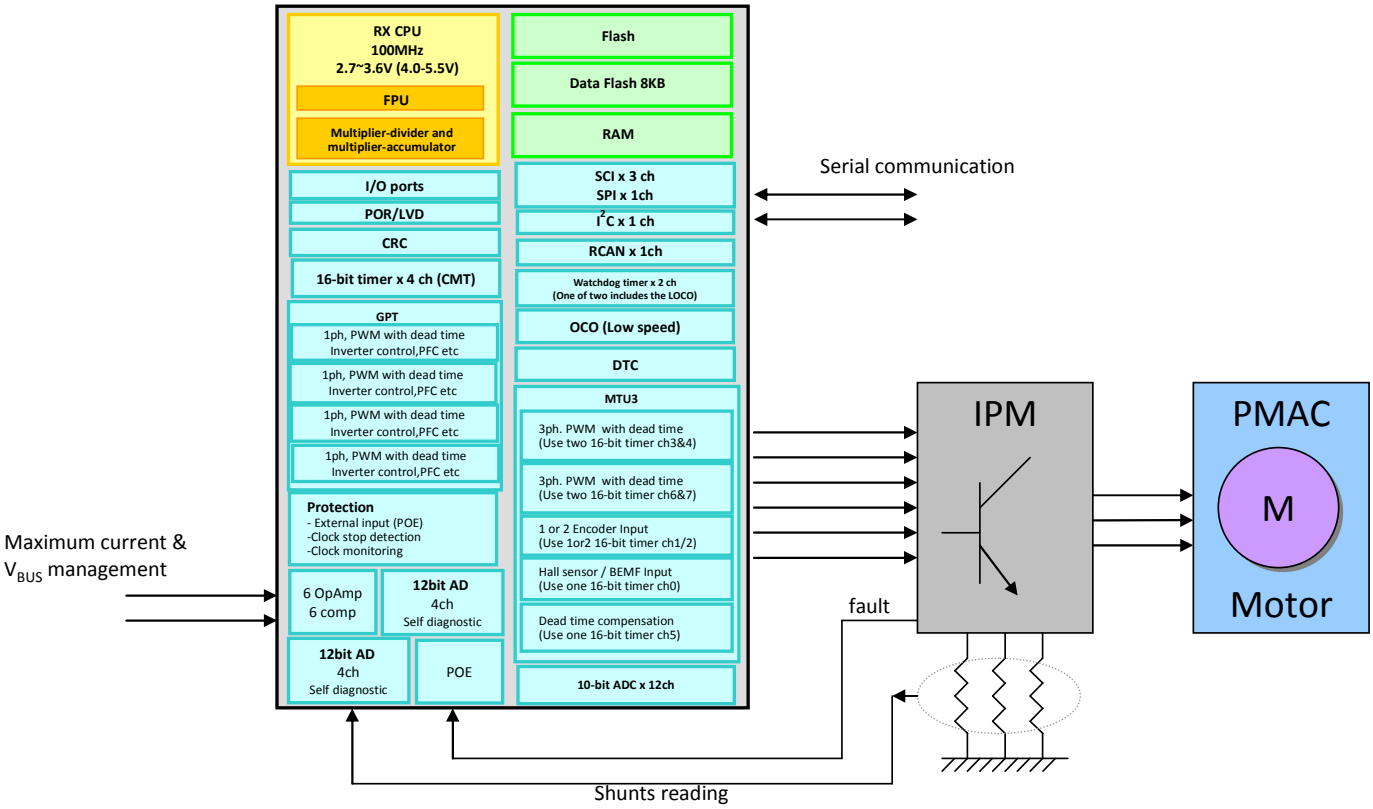
Functions

- Enhanced PWM resolution with MTU3, enhanced PWM functionality with GPT
- 12-bit A/D converter (1µs) : 4 channels x 2 unit , 10-bit A/D converter (1µs) : 12 channels x 1 unit
- Three S/H circuits for each unit: Three shunts control enable
- Double data registers for each unit: 1 shunt control enable
- Programmable gain Operational amplifier, Window comparator for Voltage monitoring
- CAN option

Large-capacity flash memory units capable of high-speed operation are included as on-chip memory, significantly reducing the cost of configuring systems.

The main application fields of this microcontroller are: industrial equipment, household electrical appliances, machines requiring motor control, and inverter-powered machines.

Please find below the block diagram of the RX62T and the role of each peripherals.

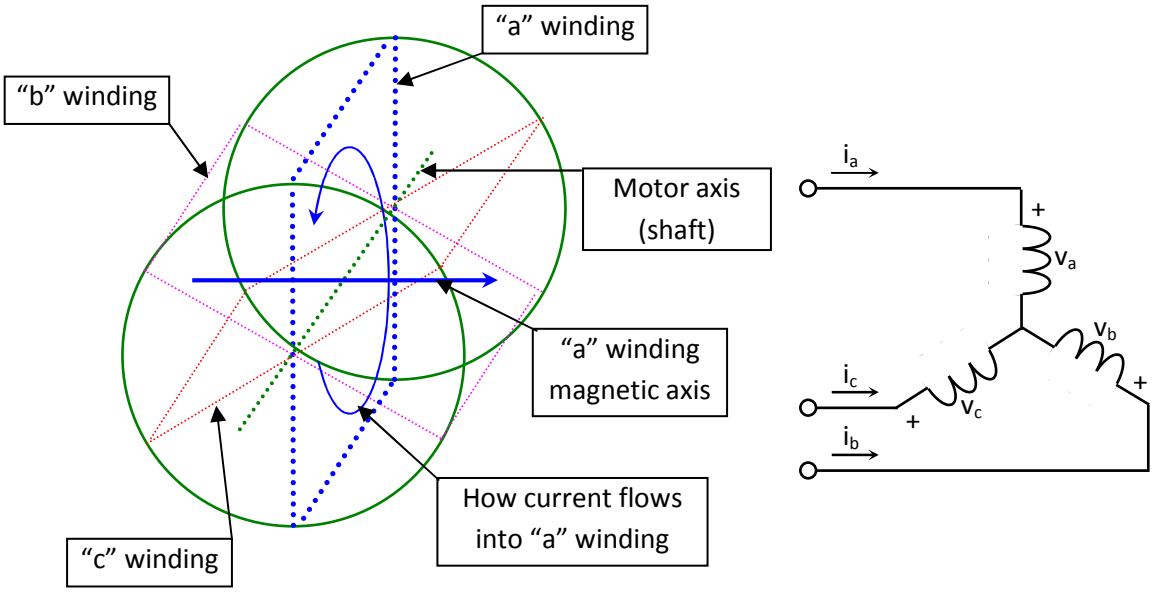


10. Permanent magnets AC Brushless motor model

The synchronous permanent magnets motor (e.g. sinusoidal Brushless motor) is widely used in the industry. More and more home appliance makers are now using such AC Brushless motor, mainly because of the intrinsic motor efficiency.

The permanent magnet motor is made with few components:

1. A *stator* formed by stacking sheared metal plates where internally the copper wiring is wound, constructing the stator winding
2. A *rotor* in which permanent magnets are fixed
3. Two covers with ball bearings that keep together the stator and the rotor; the rotor is free to rotate inside the stator



The working principle is quite simple: if we supply the motor with a three-phase system of sinusoidal voltages, at constant frequency, in the stator windings flow sinusoidal currents, which create a rotating magnetic field.

The permanent magnets in the rotor tend to stay aligned with the rotating field, so the rotor rotates at synchronous speed.

The main challenge in driving this type of motor is to know the rotor position in real-time, so mainly implementation are using a position sensor or a speed sensor.

In our implementation, the system is using either one or three shunts to detect the rotor position in real-time.

Let's analyse the motor from a mathematic point of view.

If we apply three voltages $v_a(t)$, $v_b(t)$, $v_c(t)$ to the stator windings, the relations between phase voltages and currents are:

$$v_a = R_S i_a + \frac{d\lambda_a}{dt}$$

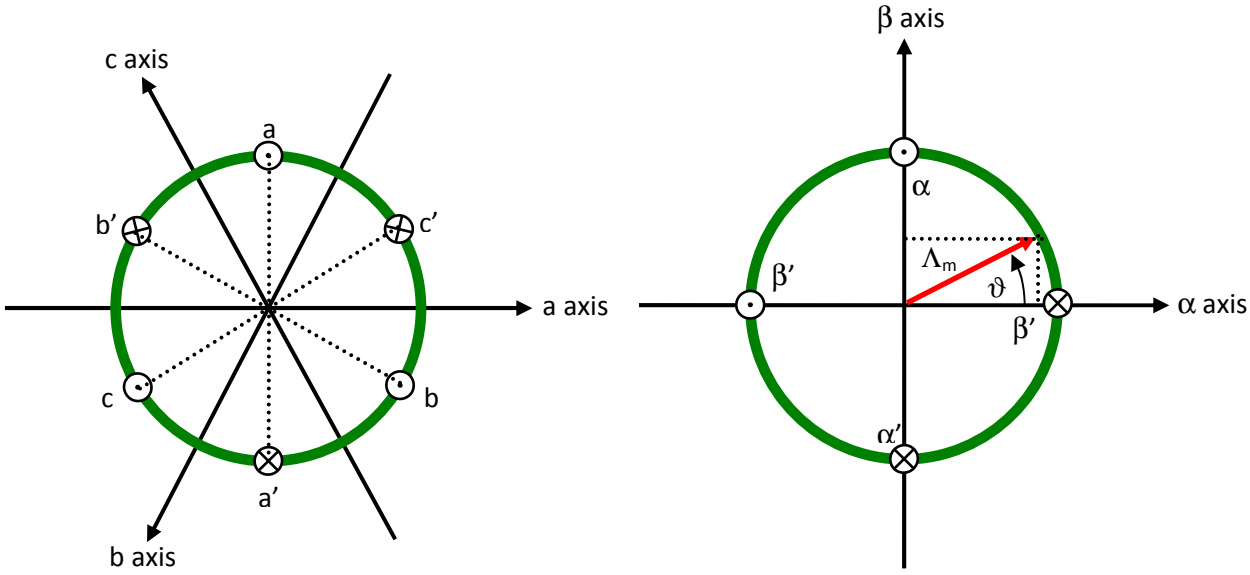
$$v_b = R_S i_b + \frac{d\lambda_b}{dt}$$

$$v_c = R_S i_c + \frac{d\lambda_c}{dt}$$

- λ_i is the magnetic flux linkage with the i-th stator winding

- R_S is the stator phase resistance (the resistance of one of the stator windings)

The magnetic flux linkages λ_i are composed by two items, one due to the stator currents, one to the permanent magnets.



Real axes (a, b, c) and equivalent ones (α, β); a fixed amplitude vector can be completely determined by its position respect the (α, β) system (angle ϑ)

The permanent magnet creates a magnetic field that is constant in amplitude and fixed in position in respect to the rotor. This magnetic field can be represented by vector Λ_m whose position in respect to the stator is determined by the angle ϑ between the vector direction and the stator reference frame.

The contribution of the permanent magnets in the flux linkages depends on the relative position of the rotor and the stator represented by the mechanical-electric angle ϑ.

It is, in every axis, the projection of the constant flux vector Λ_m in the direction of the axis:

$$\lambda_a = L i_a + \Lambda_m \cos(\vartheta)$$

$$\lambda_b = L i_b + \Lambda_m \cos(\vartheta - 2\pi/3)$$

$$\lambda_c = L i_c + \Lambda_m \cos(\vartheta - 4\pi/3)$$

Supposing that the rotor is rotating at constant speed ω (that is: ϑ(t) = ωt) the flux linkages derivatives can be calculated, and we obtain:

$$v_a = R_S i_a + L\frac{di_a}{dt} - \omega\Lambda_m \sin(\vartheta)$$
$$v_b = R_S i_b + L\frac{di_b}{dt} - \omega\Lambda_m \sin(\vartheta - 2\pi/3)$$
$$v_c = R_S i_b + L\frac{di_b}{dt} - \omega\Lambda_m \sin(\vartheta - 4\pi/3)$$

A “three phases system” may be represented by an equivalent “two phases system”. So the by using specific transformations, our three equations system is equivalent to a two equations system. It is basically a mathematical representation in a new reference coordinates system.

In the two phases (α,β) fixed system the above equations become:

$$v_\alpha = R_S i_\alpha + \frac{d\lambda_\alpha}{dt}$$
$$v_\beta = R_S i_\beta + \frac{d\lambda_\beta}{dt}$$

For the magnetic field equations, we got:

$$\lambda_\alpha = Li_\alpha + \lambda_{\alpha m} = Li_\alpha + \Lambda_m \cos(\vartheta)$$
$$\lambda_\beta = Li_\beta + \lambda_{\beta m} = Li_\beta + \Lambda_m \sin(\vartheta)$$

After performing the derivation:

$$\frac{d\lambda_\alpha}{dt} = L\frac{di_\alpha}{dt} - \omega\Lambda_m \sin(\vartheta) = L\frac{di_\alpha}{dt} - \omega\lambda_{\beta m}$$
$$\frac{d\lambda_\beta}{dt} = L\frac{di_\beta}{dt} + \omega\Lambda_m \cos(\vartheta) = L\frac{di_\beta}{dt} + \omega\lambda_{\alpha m}$$

Finally, we obtain for the voltages in (α,β) system:

$$v_\alpha = R_S i_\alpha + L\frac{di_\alpha}{dt} - \omega\lambda_{\beta m}$$
$$v_\beta = R_S i_\beta + L\frac{di_\beta}{dt} + \omega\lambda_{\alpha m}$$

A second reference frame is used to represent the equations as the frame is turning at the rotor speed. So the “d” axis is chosen in the direction of the magnetic vector Λ_m, and with the “q” axis orthogonal to the “d” axis. The new reference system is (d, q).

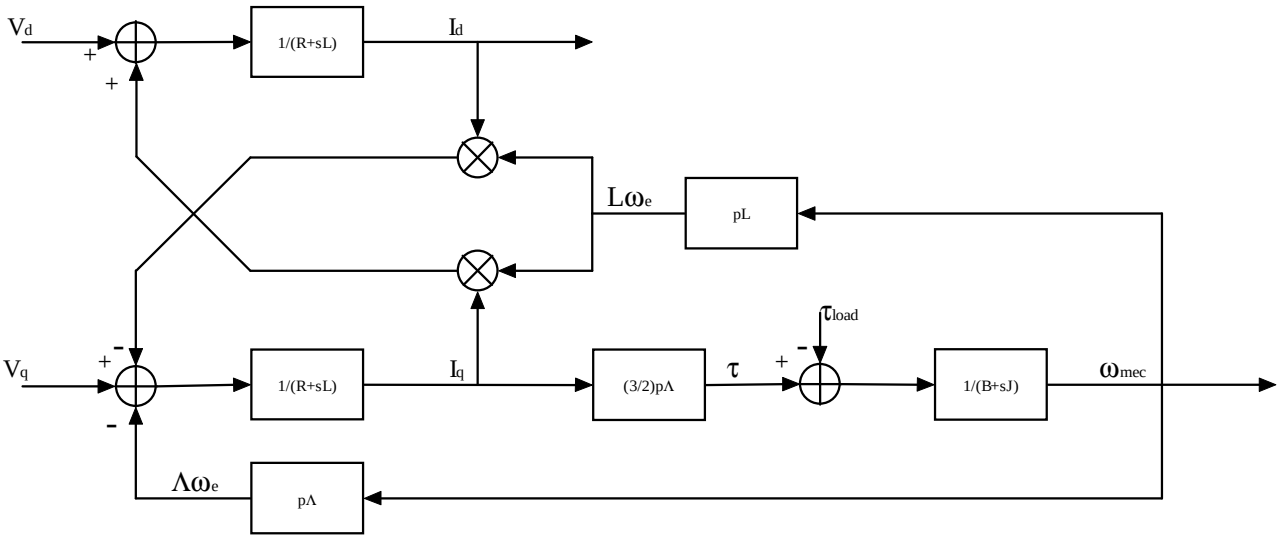
The reference frame transformations from the (α,β) system to the (d, q) system depends on the instantaneous position angle ϑ

So we obtain two inter-dependant equations in the (d, q) system:

$$v_d = R_S i_d + L\frac{di_d}{dt} - \omega L i_q$$

$$v_q = R_S i_q + L\frac{di_q}{dt} + \omega L i_d + \omega \Lambda_m$$

These two equations represent the mathematical motor model.



A control algorithm which wants to produce determined currents in the (d, q) system must impose voltages given from the formulas above.

This is ensured by closed loop PI control on both axis “d” & “q” (Proportional Integral).

Since there is a mutual influence between the two axes, decoupling terms can be used.

In the block scheme the mechanic part is included, where “p” is the number of pole pairs, while “B” represents friction, “J” the inertia, “τ_{load}“ the load torque and “τ” the motor torque.

$$\tau = \frac{3}{2} \times p \times \Lambda$$

The angular speed ω is represented in the scheme as ω_e to distinguish the electrical speed from the mechanical one.

Let’s now consider the equations we have seen in (α,β) system:

$$v_\alpha = R_S i_\alpha + \frac{d\lambda_\alpha}{dt}$$
$$v_\beta = R_S i_\beta + \frac{d\lambda_\beta}{dt}$$

These equations show that magnetic flux can be obtained from applied voltages and measured currents simply by integration:

$$\lambda_\alpha = \lambda_{\alpha 0} + \int_0^t (v_\alpha - R_S i_\alpha) dt$$
$$\lambda_\beta = \lambda_{\beta 0} + \int_0^t (v_\beta - R_S i_\beta) d$$

Furthermore:

$$\Lambda_m \cos(\vartheta) = \lambda_\alpha - L i_\alpha$$
$$\Lambda_m \sin(\vartheta) = \lambda_\beta - L i_\beta$$

If the synchronous inductance L is small, the current terms can be neglected, if not they have to be considered. In general:

$$x = \Lambda_m \cos(\vartheta) = \lambda_\alpha - L i_\alpha = \lambda_{\alpha 0} + \int_0^t (v_\alpha - R_S i_\alpha) dt - L i_\alpha$$
$$y = \Lambda_m \sin(\vartheta) = \lambda_\beta - L i_\beta = \lambda_{\beta 0} + \int_0^t (v_\beta - R_S i_\beta) dt - L i_\beta$$

So in the (α,β) system phase we obtain from the flux components:

$$\vartheta = \arctan(x/y)$$

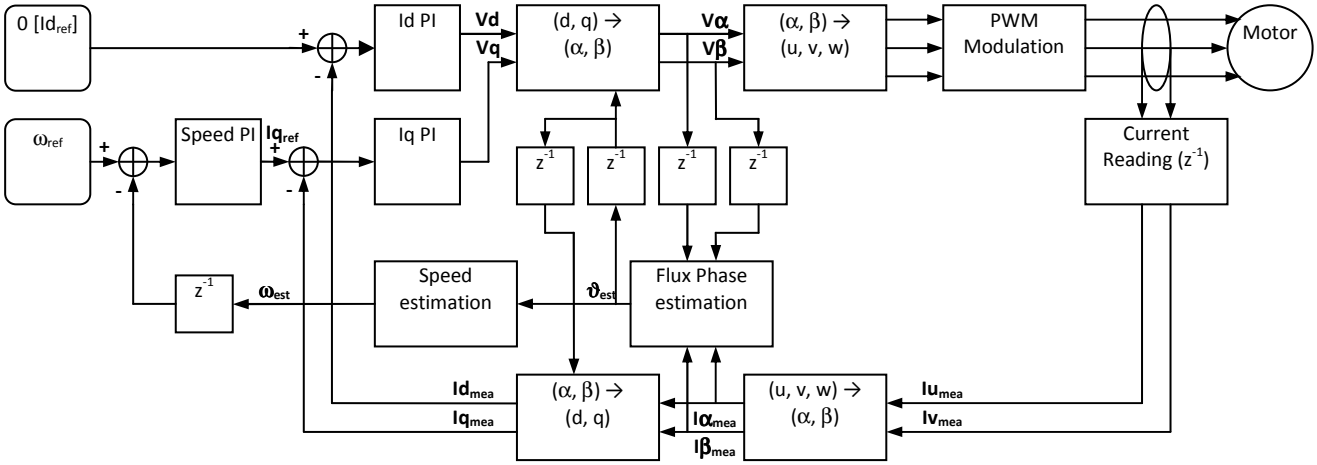
The system speed ω can be obtained as the derivative of the angle ϑ.

$$\omega = \frac{d}{dt}\vartheta(t)$$

Based on this, a sensorless control algorithm was developed to give the imposed phase voltages, to measure phase currents, to estimate the angular position ϑ and finally the system speed.

11. Sensorless Field Oriented Control Algorithm

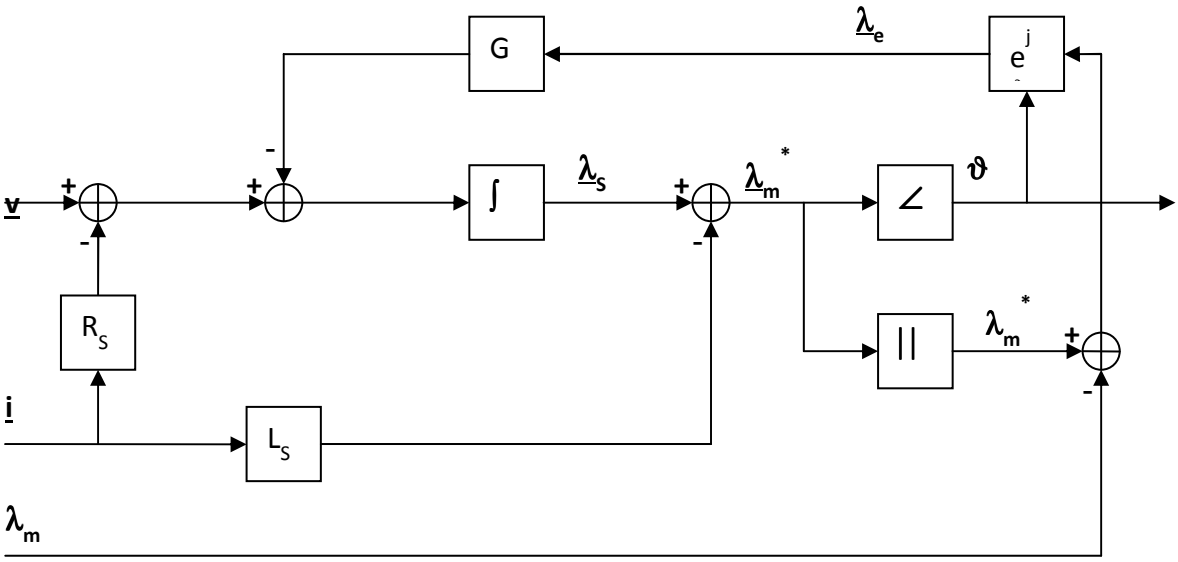
Please, find below the sensorless FOC algorithm block diagram.



The only difference between the three shunts configuration and the single shunt one is in the “Current Reading” block, the rest of the algorithm remains the same.

12. Flux Feedback Gain

The block scheme of the exact BEMF integration method for flux position estimation is the following:



The inputs of the system are the imposed voltage vector V and the measured current vector I.

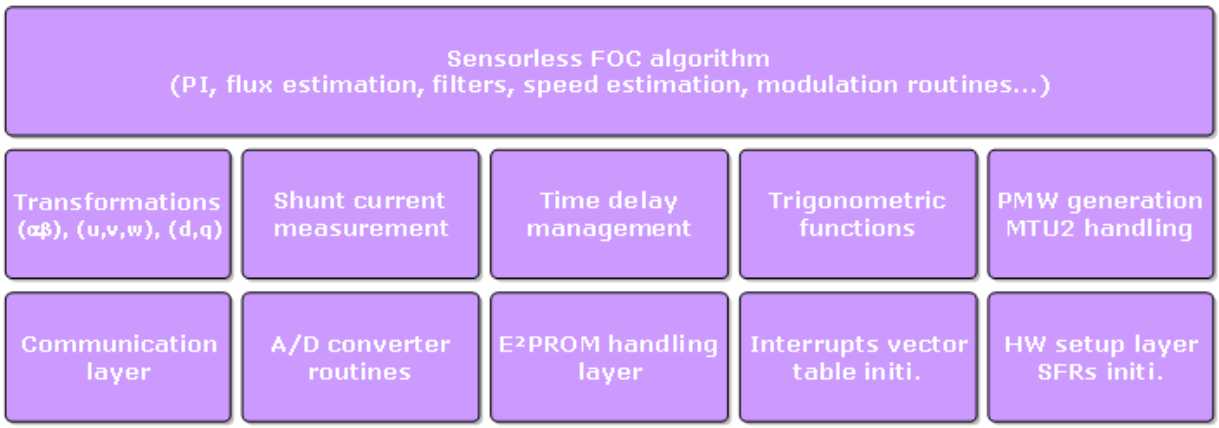
The motor phase resistance R_s, the synchronous inductance L_s and the permanent magnet flux amplitude λ_m are known as parameters and motor specific.

The integral operation is corrected with a signal obtained modulating accordingly with the estimated phase the error between the estimated flux amplitude and the amplitude of the permanent magnets flux. The gain of this correction is indicated with G and it is this feedback which avoids the integral divergence due to the errors, offsets and so on. The higher G is, the higher is the correspondence between the estimated amplitude and the theoretical one, but the larger can be the induced phase error. The choice of G is a compromise, in order to guarantee that the integral remains close to its theoretical value, but free enough to estimate the correct system phase.

13. Software description

The software of the YROTATE-IT-RX62T kit is working on the RX62T microcontroller clocked at 100MHz. It is a fast and powerful device for this class of algorithm.

This allows the user to realize virtually what he wants in addition.



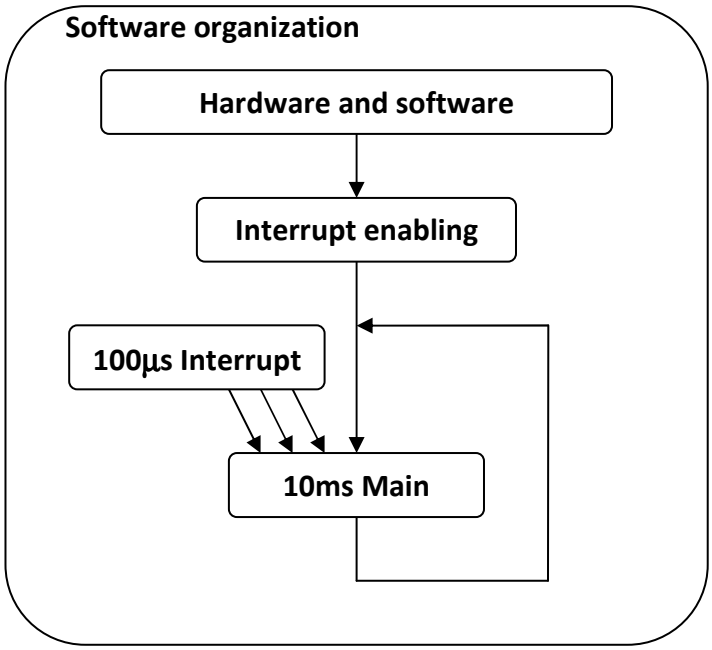
The total software uses the following resources:

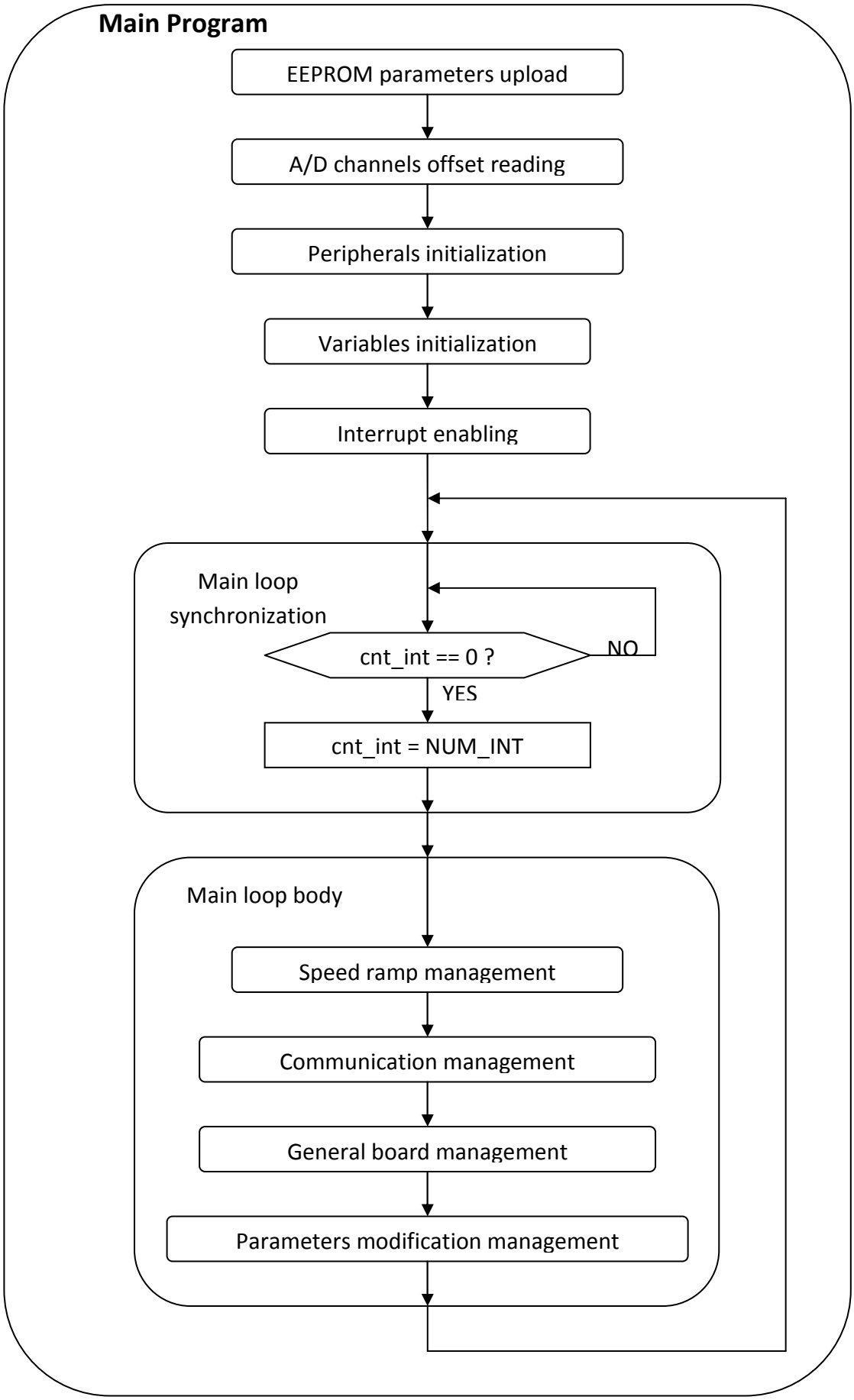
1) FLASH : 18Kbytes

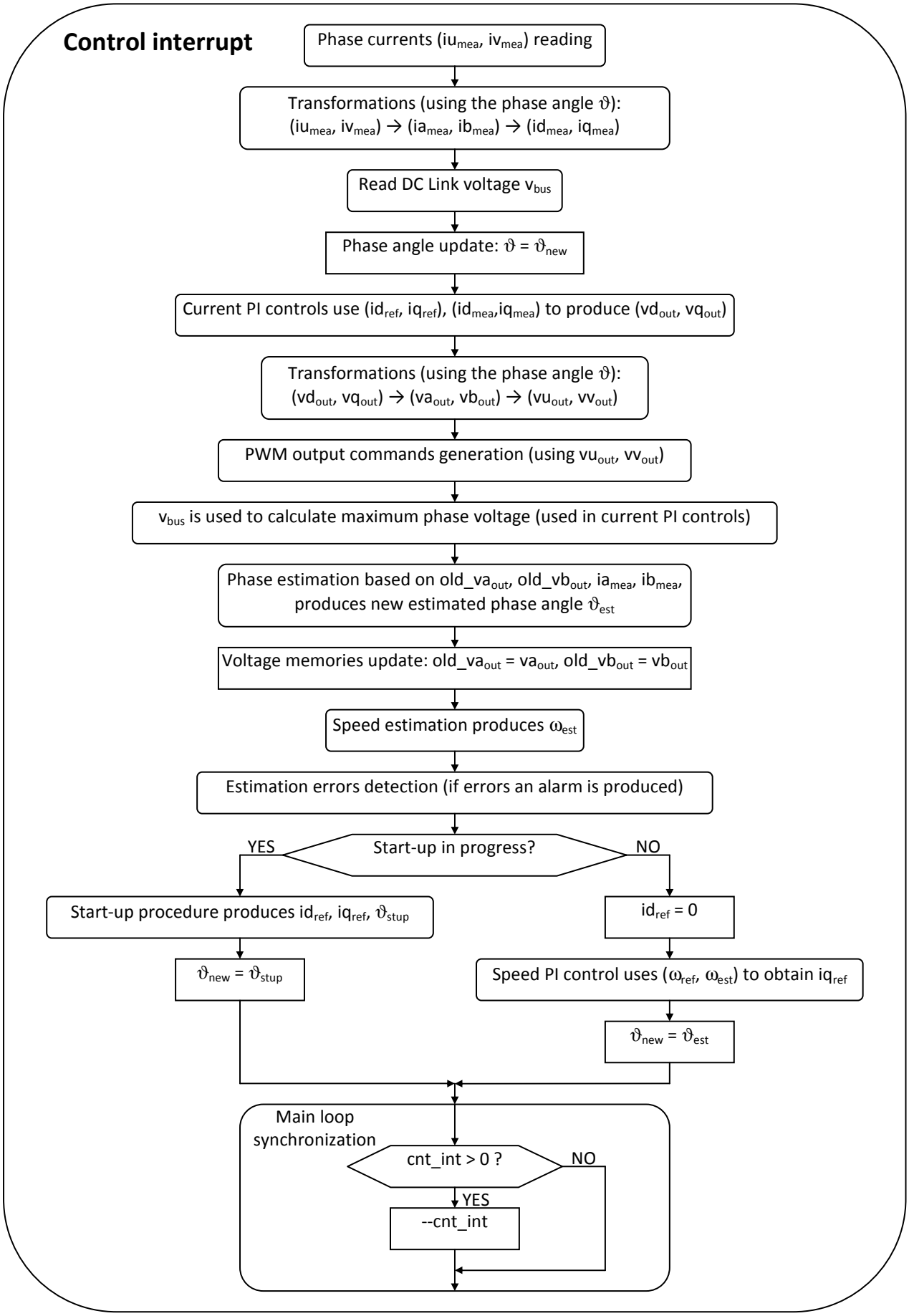
2) RAM : 3Kbytes

Please note that these data include also the communication interface and the reference board management.

The following flowcharts show the software implementation of the motor control part of the software.




Main Program
EEPROM parameters upload
A/D channels offset reading
Peripherals initialization
Variables initialization
Interrupt enabling
Main loop synchronization
cnt_int == 0 ?
NO
YES
cnt_int = NUM_INT
Main loop body
Speed ramp management
Communication management
General board management
Parameters modification management


Control interrupt
Phase currents (iu_mea, iv_mea) reading
Transformations (using the phase angle ϑ):
(iu_mea, iv_mea) → (ia_mea, ib_mea) → (id_mea, iq_mea)
Read DC Link voltage v_bus
Phase angle update: ϑ = ϑ_new
Current PI controls use (id_ref, iq_ref), (id_mea,iq_mea) to produce (vd_out, vq_out)
Transformations (using the phase angle ϑ):
(vd_out, vq_out) → (va_out, vb_out) → (vu_out, vv_out)
PWM output commands generation (using vu_out, vv_out)
v_bus is used to calculate maximum phase voltage (used in current PI controls)
Phase estimation based on old_va_out, old_vb_out, ia_mea, ib_mea,
produces new estimated phase angle ϑ_est
Voltage memories update: old_va_out = va_out, old_vb_out = vb_out
Speed estimation produces ω_est
Estimation errors detection (if errors an alarm is produced)
YES
Start-up in progress?
NO
Start-up procedure produces id_ref, iq_ref, ϑ_stup
id_ref = 0
ϑ_new = ϑ_stup
Speed PI control uses (ω_ref, ω_est) to obtain iq_ref
ϑ_new = ϑ_est
Main loop
synchronization
cnt_int > 0 ?
NO
YES
--cnt_int

The CD-ROM of the motor control kit **YROTATE-IT-RX62T** contains two projects available in zipped files called:

1) **File name: "MCRP07_RX62T_intPS_v7.zip"** loaded by default on the kit PCB to manage low voltage motor using the internal power stage made of MOSFETs and available on the board.

By default, the embedded software is tuned to drive the low voltage motor called: **FL28BL38** and delivered in the kit. Please find below a snapshot of the header file "customize.h" where all the motor parameters are located.

```
// FL28BL38-HS motor default parameters
#define RPM_MIN_DEF     3000  //  200 < X <  5000 // min speed in rpm
#define RPM_MAX_DEF     13000 // 1000 < X < 20000 // max speed in rpm
#define R_ACC_DEF      2000  //    1 < X < 10000 // accel. ramp in rpm/sec
#define R_DEC_DEF      2000  //    1 < X < 10000 // accel. ramp in rpm/sec
#define C_POLI_DEF      2    //    1 < X <    24 // polar couples number
#define I_START_DEF     200   //    0 < X < 15000 // startup current in A(pk)/AMP_DIV
#define I_MAX_DEF      400   //    0 < X < 15000 // max current in A(pk)/AMP_DIV
#define R_STA_DEF      220   //    0 < X < 30000 // stator phase resistance in Ohm/OHM_DIV
#define L_SYN_DEF      25    //    0 < X < 30000 // synchronous inductance in Henry/HEN_DIV
#define PM_FLX_DEF      30    //    0 < X < 30000 // permanent magnet flux in Weber/WEB_DIV
#define KP_CUR_DEF      20    //    0 < X < 30000 // K prop. current control
#define KI_CUR_DEF      120   //    0 < X < 30000 // K integ. current control
#define KP_VEL_DEF      50    //    0 < X < 30000 // K prop. speed control
#define KI_VEL_DEF      100   //    0 < X < 30000 // K integ. speed control
#define FB_GAIN_DEF     500   //    0 < X < 30000 // flux amplitude feedback gain
#define PHA_OFF_DEF     0   //    0 < X < 360 // offset angle
```

2) **File name: "MCRP07_RX62T_extPS_v7.zip"** has to be used with an external power stage e.g. 1.5KW, as the embedded software is using other channels of the Motor control timer. In the software driving the power stage, the "customize.h" file contains the parameters of the motor called: MB057GA240. Please find below a snapshot of the header file "customize.h" where all the motor parameters are located:

```
// MB057GA240 motor default parameters
#define RPM_MIN_DEF     300   //  200 < X <  5000 // min speed in rpm
#define RPM_MAX_DEF     3000  // 1000 < X < 20000 // max speed in rpm
#define R_ACC_DEF      1000  //    1 < X < 10000 // accel. ramp in rpm/sec
#define R_DEC_DEF      1000  //    1 < X < 10000 // accel. ramp in rpm/sec
#define C_POLI_DEF      2    //    1 < X <    24 // polar couples number
#define I_START_DEF     1000  //    0 < X < 15000 // startup current in A(pk)/AMP_RES
#define I_MAX_DEF      3000  //    0 < X < 15000 // max current in A(pk)/AMP_RES
#define R_STA_DEF      70    //    0 < X < 30000 // stator phase resistance in Ohm/OHM_RES
#define L_SYN_DEF      20    //    0 < X < 30000 // synchronous inductance in Henry/HEN_RES
#define PM_FLX_DEF      260   //    0 < X < 30000 // permanent magnet flux in Weber/WEB_DIV
#define KP_CUR_DEF      50    //    0 < X < 30000 // K prop. current control
#define KI_CUR_DEF      100   //    0 < X < 30000 // K integ. current control
#define KP_VEL_DEF      30    //    0 < X < 30000 // K prop. speed control
#define KI_VEL_DEF      400   //    0 < X < 30000 // K integ. speed control
#define FB_GAIN_DEF     100   //    0 < X < 30000 // flux amplitude feedback gain
#define PHA_OFF_DEF     0   //    0 < X < 360 // offset angle
```

Furthermore, both projects are compiled and the object code is available on the CD-ROM and can be directly loaded into the RX62T microcontroller. The file name is called: "**MCRP07_RX62T.mot**" in each project.

Such feature is used to avoid launching the full IDE and recompiling the full project.

14. Application customization using “customize.h” file

Please find below snapshot of the file “customize.h” which contents many interesting options and details about the RX62T embedded software. Feel free to modify it and recompile the source code in order to use the new values. The “customize.h” is a file containing some macros used to specify important program parameters. The most important of them are listed below.

```
// eeprom (comment if not used)
#define EEPROM_USED

// debug (comment after first control)
//#define MACRO_DEBUG

// open loop debug (comment in final release)
#define DEBUG_OPENLOOP

// DC current vector setting debug mode (comment in final release)
//#define DCCUR_SETTING

// ADDITIONAL FEATURE: current PI manual tuning (comment if not used)
#define CPI_TUN

// ADDITIONAL FEATURE: current PI automatic tuning (comment if not used)
#define CPI_AUT

// ADDITIONAL FEATURE: motor parameters auto-identification (comment if not used)
#define MOT_IDENT

// ADDITIONAL FEATURE: oscilloscope window in GUI management (comment if not used)
#define OSC_WIN

// sampling period and modulation setting
// NOTE: This relation MUST be satisfied: PWM_FREQ_CUSTOM=N*SAM_FREQ_CUSTOM where 1<=N<=8
#define PWM_FREQ_CUSTOM    16000 // PWM Frequency [Hz], 2000<=PWM_FREQ_CUSTOM<=20000
#define SAM_FREQ_CUSTOM    16000 // Sampling Frequency [Hz], 2000<=SAM_FREQ_CUSTOM<=20000

// lower arms ON when not rotating
//#define DEF_LOW_ON

// PI gains amplification
#define AMP_KPCUR      4.0f
#define UAMP_KICUR       128.0f
#define AMP_KICUR      ((float)(1.0/UAMP_KICUR)) // 0.0078125f
#define AMP_KPVEL      16384.0f
#define AMP_KIVEL      2048.0f

// parameters measurement units resolution
#define AMP_RES        1000.0f // current parameters expressed in ampere/AMP_RES
#define VOL_RES        10.0f // voltage parameters expressed in volt/VOL_RES
#define OHM_RES        100.0f  // resistance parameters expressed in ohm/OHM_RES
#define HEN_RES        10000.0f// inductance parameters expressed in henry/HEN_RES
#define WEB_RES        10000.0f// flux parameters expressed in weber/WEB_RES
```

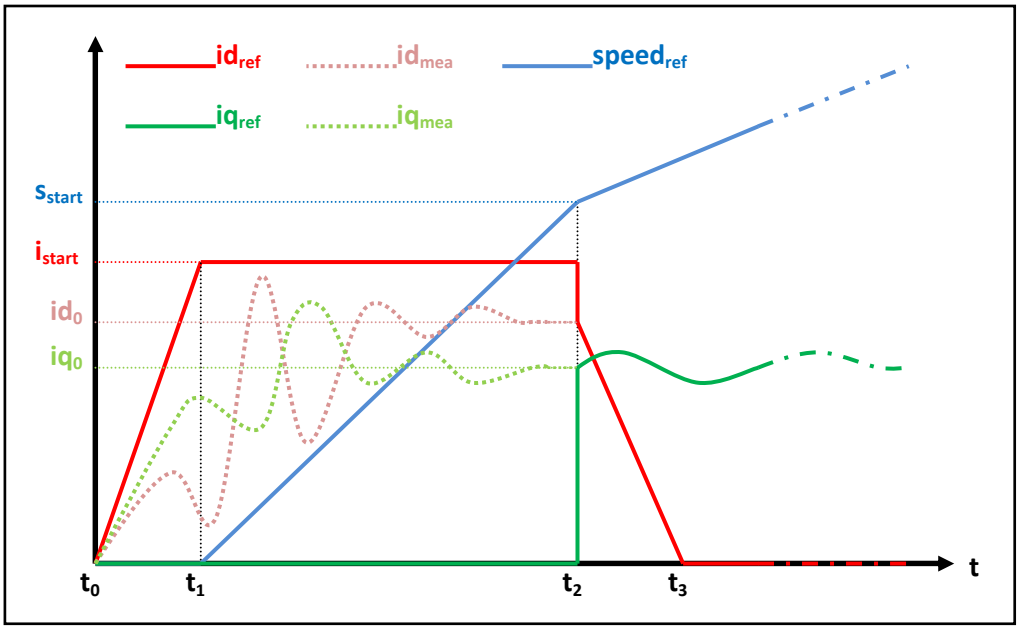
```
130 // startup timing definitions
131 #define STUP_CUR_RT_MS     1000  // current rising time during startup alignment [ms]
132 #define STUP_SPE_RT_MS     1000  // speed rising time (from 0 to min speed) during startup [ms]
133 #define STUP_CUR_FT_MS     1000  // d current falling time after startup [ms] (assuming id=i_start)
134
135 // rotation direction
136 //#define ROT_REV
137
138 // modulation
139 #define DTC_REF            // uses current references in calculations (else uses measurements)
140 //#define ICOMP            // uses the currents to compensate modulation
141 #define CENTERED           // centered modulation
142 //#define OVERMOD          // overmodulation
143
144 // inverter non-linearities compensation
145 #define INLCOMP            // inverter non linearities compensation
146 //#define INL_DET          // non-linearity table determination (comment in final release)
147
148 // other control parameters
149 #define MAXERR_RPM      300.0f  // maximum error for ramp limitation and PI clamping
150 #define K_MARGV0      0.90f // max_d_volt/max_volt ratio
151
152 // speed PI error clamping
153 #define SPEEDPI_ERRCLAMP      // input to speed PI is clamped to MAXERR_RPM
154
155 // DC bus voltage limit for ramp limitation
156 //#define VB_RAMP          // comment this to avoid ramp limitation due to vbus
157 #define VBUS_LIM      360.0f  // dc bus voltage limit [V]
158 #define VBUS_LIMH     370.0f  // dc bus voltage limit [V]
159 #define VBUS_LIML     360.0f  // dc bus voltage limit [V]
160 #define K_RAMPLIM     0.9f  // ramp limitation gain
161
162 // ramp clamp (comment if you don't want it)
163 #define RAMP_CLO           // clamp if heavy speed error
164
165 // flux weakening
166 #define FLUXWEAK           // comment to avoid flux weakening
167 #define K_MARGV1      0.95f // percent of available voltage at which FW begins
168 #define K_MARGIO      0.80f // max_d_cur/max_cur ratio
169 #define DCUR_DT       1.50f // d current variation rate [A/s] during FW
170
171 // speed lowpass filter cut-off frequency f0 (time constant will be tau=(1/w0)=(1/(2PIf0)
172 #define SPEED_LP_CUTOFF_HZ  100.0f  // cut-off frequency [Hz]
173
174 // flux estimation method selection
175 //#define APP_INT          // uncomment this if you prefer approximated integration
176
```

15. Start-up procedure

When the motor is in stand-still, the phase of the permanent magnet flux vector cannot be detected with the used algorithm. So an appropriate start-up procedure has to be applied.

The idea is to move the motor in feed-forward (with higher current than that required to win the load), till a speed at which the estimation algorithm can work. Then the system can be aligned to the estimated phase, and the current can be reduced to the strictly necessary quantity.

The following graph illustrates the strategy used (the suffix "$_{ref}$" stands for *reference*, the suffix "$_{mea}$" stands for *measured*).



Referring to the graph, the startup procedure (in case of three shunts current reading) is described below.

a) At the beginning t_0, the system phase is unknown. No current is imposed to the motor; the system phase is arbitrarily decided to be ϑ_a=0. All the references: id_{ref}, iq_{ref} and $speed_{ref}$ are set to zero.

b) From the moment t_0, while the iq_{ref} and the $speed_{ref}$ are maintained to zero, id_{ref} is increased with a ramp till the value i_{start} is reached at the moment t_1.

The references are referred to an arbitrary (d_a, q_a) system based on the arbitrary phase ϑ_a. From this moment, the phase estimation algorithm begins to be performed, and the estimated phase ϑ_{est} is used to calculate the components of the measured current, referred to the (d, q) system based on the estimated phase, id_{mea} and iq_{mea}. The components of the current referred to the arbitrary (d_a, q_a) system are controlled to follow the references by the current PI controllers. On the other hand, since the phase ϑ_{est} is still not correctly estimated, id_{mea} and iq_{mea} have no physical meaning. Even if they are not shown in the graph, the applied voltages are subjected to the same treatment (vd_{mea} and vq_{mea} are calculated in the algorithm).

c) At t = t_1, while iq_{ref} is maintained to zero and id_{ref} is maintained to its value i_{start}, $speed_{ref}$ is increased with a ramp till the value s_{start} is reached at the t = t_2. The system phase $\vartheta_a(t)$ is obtained simply by integration of $speed_{ref}$; in the meanwhile, the phase estimation algorithm begins to align with the real system phase.

Furthermore id_{mea} and iq_{mea} begin to be similar to the real flux and torque components of the current. The real components are supposed to be id_0 and iq_0 (those values are obtained applying a low-pass filter to id_{mea} and iq_{mea}).

The interval (t_2-t_1) is the start-up time, and it is supposed to be large enough to allow the estimation algorithm to reach the complete alignment with the real phase of the system.

d) At $t = t_2$, the phase estimation process is supposed to be aligned. At this point a reference system change is performed: from the arbitrary (d_a, q_a) reference to the (d, q) reference based on the estimated phase ϑ_{est}.

The current references are changed to the values id_0 and iq_0, and all the PI controllers are initialized with these new values. The speed PI integral memory is initialized with the value iq_0, while the current PI integral memories are initialized with the analogous voltage values vd_0 and vq_0, obtained from vd_{mea} and vq_{mea}.

e) After $t > t_2$, the normal control is performed, based on the estimated phase ϑ_{est}; the speed reference is increased with the classical ramp; the id current reference is decreased with a ramp, till it reaches the value zero at the moment t_3; then it is maintained to zero; the iq current reference is obtained as output of the speed PI controller.

16. Reference system transformations in details

Find below the detailed equations used for the coordinates transformations.

$$g_\alpha = \frac{2}{3}(g_u - \frac{1}{2}g_v - \frac{1}{2}g_w) = g_a$$
$$g_\beta = \frac{2}{3}(\frac{\sqrt{3}}{2}g_v - \frac{\sqrt{3}}{2}g_w) = \frac{1}{\sqrt{3}}(g_v - g_w) = \frac{1}{\sqrt{3}}(g_u + 2g_v)$$

(u, v, w) → (α, β)

$$g_u = g_\alpha$$
$$g_v = -\frac{1}{2}g_\alpha + \frac{\sqrt{3}}{2}g_\beta = (-g_\alpha + \sqrt{3}g_\beta)/2$$
$$g_w = -\frac{1}{2}g_\alpha - \frac{\sqrt{3}}{2}g_\beta = (-g_\alpha - \sqrt{3}g_\beta)/2$$

(α, β) → (u, v, w)

$$g_d = g_\alpha \cos(\vartheta) + g_\beta \sin(\vartheta)$$
$$g_q = -g_\alpha \sin(\vartheta) + g_\beta \cos(\vartheta)$$

(α, β) → (d, q)

$$g_\alpha = g_d \cos(\vartheta) - g_q \sin(\vartheta)$$
$$g_\beta = g_d \sin(\vartheta) + g_q \cos(\vartheta)$$

(d, q) → (α, β)

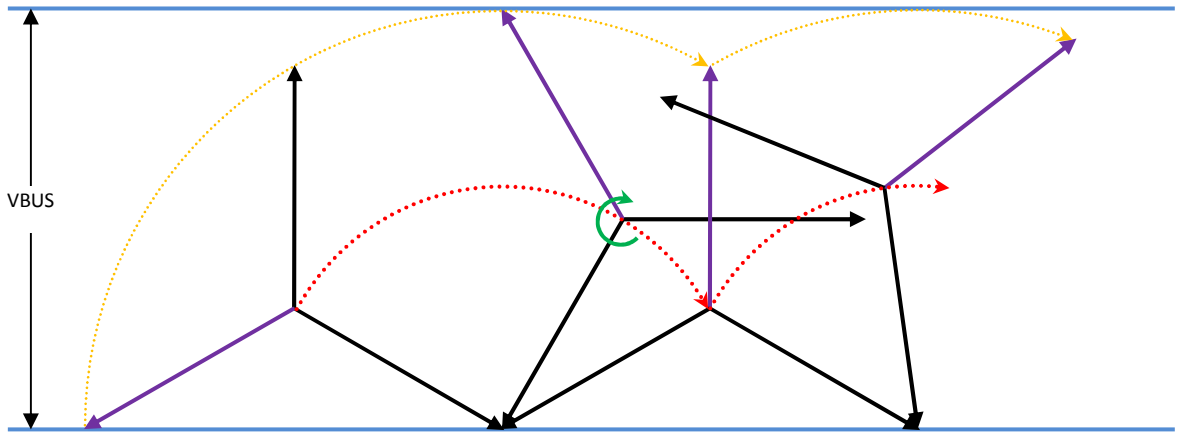
$$\left.\begin{aligned} v_u &= V\cos(\omega t + \varphi_0) \\ v_v &= V\cos(\omega t + \varphi_0 - 2\pi/3) \\ v_w &= V\cos(\omega t + \varphi_0 - 4\pi/3) \end{aligned}\right\} \leftrightarrow \left\{\begin{aligned} v_\alpha &= V\cos(\omega t + \varphi_0) \\ v_\beta &= V\sin(\omega t + \varphi_0) \end{aligned}\right\} \leftrightarrow \left\{\begin{aligned} v_d &= V\cos(\varphi_0) \\ v_q &= V\sin(\varphi_0) \end{aligned}\right\}$$

17. PWM modulation technique

Among the various possibilities, a particular form of PWM modulation was chosen. In this modulation technique, the voltages to be imposed are shifted in order to have in every moment one of the three phases of the motor connected to the system ground. This allows reducing the commutations of the power bridge of one third, in respect to other modulation techniques. In fact the phase that is connected to the system ground doesn't require any commutation, having the lower arm always on and the upper arm always off.

The method is based on the fact that, having no neutral connection, we are interested only in phase-to-phase voltages, or in the voltage differences between the phases, not in the voltage level of the single phases. This allows us to add or subtract an arbitrary quantity to the phase voltages, on condition that this quantity is the same for all the three phases. So, obtained from the algorithm the three phase voltages requests, the minimum is chosen and it is subtracted to all the three requests.

With this method, the applied voltage star center is not at a fixed level, but it is moving.



The maximum phase-to-phase voltage that can be obtained (without distortion of the sinusoidal waveform) with this method is equal to the DC Link voltage, as in other methods (like Space Vector Modulation).

18. PC Graphical User Interface

The User Interface is easily installed via the CD-ROM installer. The PC Interface is using the optically isolated USB connection to powered the board and communicate with it.

Once the Motor Control PC GUI is installed based on the explanations of the Quick Start Guide, please click on the “Speed Control” button to display the following window:

Please find below the description of the Alarm codes coming from the PC GUI:

Alarm 1:
The alarm 1 is called “EEPROM alarm” and described in the software by “EQP_ALL”. This alarm is set when one or more EEPROM parameters are higher than the maximum allowed value or lower than the minimum allowed value. The LED DL4 is quickly blinking on the main board to indicate that an alarm is set.
The maximum and minimum values are specified in the two constants tables called: "par_max[]" "par_min[]" in the "ges_eqp.h" header file. Another root cause for the alarm 1 is the EEPROM hardware failure when the error is accessed in read or write mode.
When this alarm is active, the access to the EEPROM is restricted. To reset the alarm the default parameters set should be reloaded in the EEPROM. By using the PC GUI and the parameters setting window, it becomes possible to clean the EEPROM content. The first step is to write the magic number “33” in the first parameter n°00. The second step is to reset the board by pressing the reset button on the PCB or switching off the power supply.
At this point a coherent set of parameters is loaded and the alarm should disappear.

Finally, if the alarm is produced by a hardware failure of the EEPROM itself, then the board needs to be repaired

Alarm 2:
The alarm 2 is called “hardware overcurrent” and described in the software by “FAULT_ALL”. This alarm is produced by the microcontroller peripheral called Port Output Enable (POE) in case of external overcurrent signal. The hardware overcurrent is producing a falling edge input on the POE pin. Furthermore, if the hardware level of the PWM output pin is not coherent with the level imposed by software, the alarm 2 will also be triggered.
The LED DL4 is quickly blinking on the main board to indicate that an alarm is set.
The only way to clear the alarm is to reset the board by using the reset button on the PCB or by switching off the supply and on again.
Finally, one of the root causes of the Alarm 2 is a hardware defect or a wrong behavior of the current control. So please also check the setting of the current PI coefficients that are stored in EEPROM or used in real-time.

Alarm 3:
The alarm 3 is called “loss of phase” and described in the software by “TRIP_ALL”. This alarm is produced when the sensorless position detection algorithm is producing inconsistent results. It means that the rotor position is unknown due to a lack of accuracy, so the motor is stopped.
The LED DL4 is quickly blinking on the main board to indicate that an alarm is set.
This alarm can be reset by setting the speed reference to zero on the PC GUI.

Please find below an extract of the header file “const_def.h”:

```
#define EQP_ALL          1      // EEPROM alarm code
#define FAULT_ALL        2      // overcurrent hardware alarm code (POE)
#define TRIP_ALL         3      // loss of phase alarm code
```

Finally, the PC GUI button called “parameters setting” is used to enter and modify the motor and applications parameters. The list of parameters that can be changed in real-time are displayed in the PC GUI.

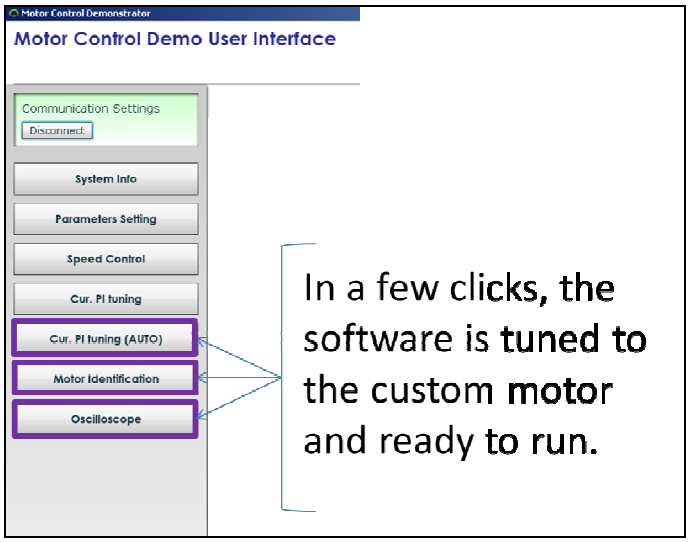
In case of issue or inconsistent parameters, please enter the magic number “33” in the first line called: “00. Default Parameters setting “and click the button “Write” and perform a Reset of the microcontroller board.

Click on the “Reload” button to get the parameters by default stored into the EEPROM and define in the “customize.h” file.

Please check that the first parameters like the speed range and the number of polar couples are in-line with the motor to be tuned.

19. Motor Auto-calibration using the PC GUI

The full calibration of any 3-phase AC Brushless motor can be performed automatically using the PC Graphical User Interface. Three specific buttons are now available for and shown below:



In terms of AC Brushless motor driven in sinusoidal mode and FOC algorithm, the most important parameters to tune are:

1. Current PI parameters: Propotional K_p and Integral K_i

2. Motor parameters: Stator resistance R_s, the synchronous inductance L_s, and the Permanent Magnet flux Λ_m.

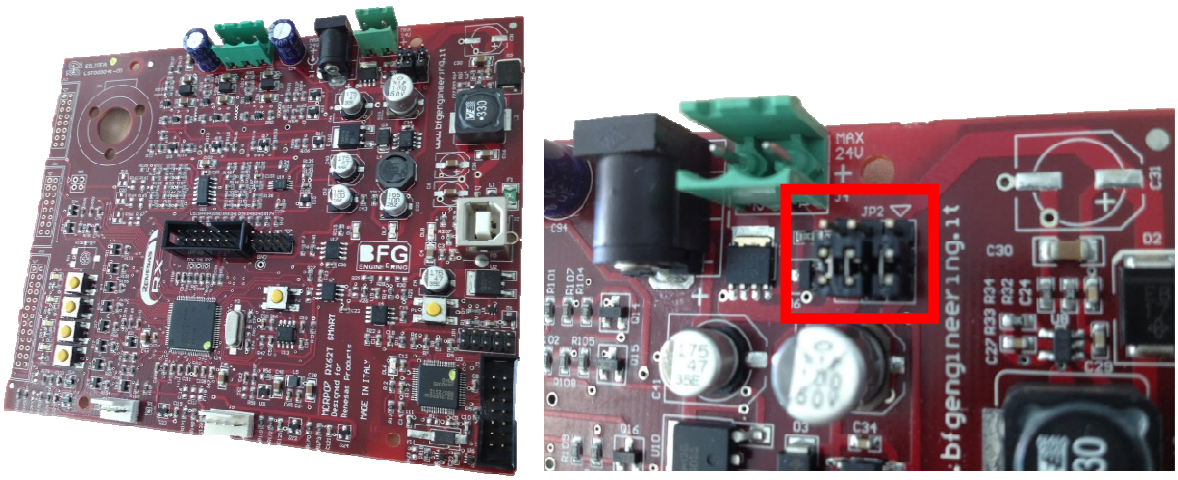
Let's tune step by step a real low voltage PMSM motor using the internal power stage with Mosfets.

a) The BLAC Motor selected is the following one:

Motor type: **MB057GA240**
Maximum current: **3.5A**
Bus Voltage: **50V**
Maximum speed: **5000 RPM**
Number of pole pair: **2**

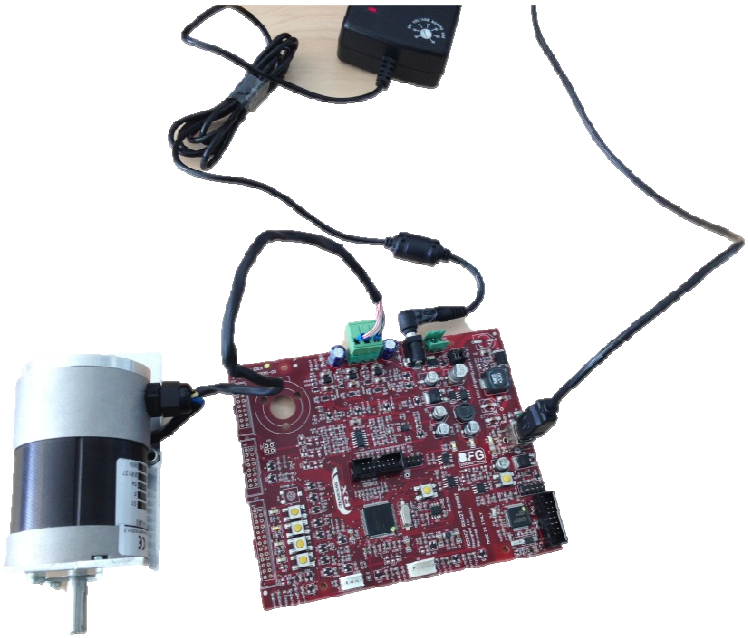
MOTOR PARAMETERS @25°C			
	TOL.	UNITS	VALUE
MAX. OPERATING SPEED (Snl)	MAX.	R.P.M.	5000
CONTINUOUS TORQUE (Tc)	MAX.	OZ-IN	38
PEAK TORQUE (Tp)	MAX.	OZ-IN	114
CONTINUOUS CURRENT (Ic)	MAX.	AMPS	3.5
PEAK CURRENT (Ip)	MAX.	AMPS	10.6
TORQUE SENSITIVITY (Kt)	±10%	OZ-IN/AMPS	11.9
BACK EMF CONSTANT (Ke) (L-L, D.C.)	±10%	V/K R.P.M.	8.8
D.C. RESISTANCE (Rt) (L-L)	±10%	OHMS	1.12
INDUCTANCE (L) (L-L)	±15%	mH	3.19
ROTOR INERTIA (Jo)	NOM.	OZ-IN-SEC^2	0.0017
WEIGHT	NOM.	LBS	1.78

b) Let's setup the Motor control kit for 24V external power supply: the jumper JP2 needs to be set to 2-3 position.

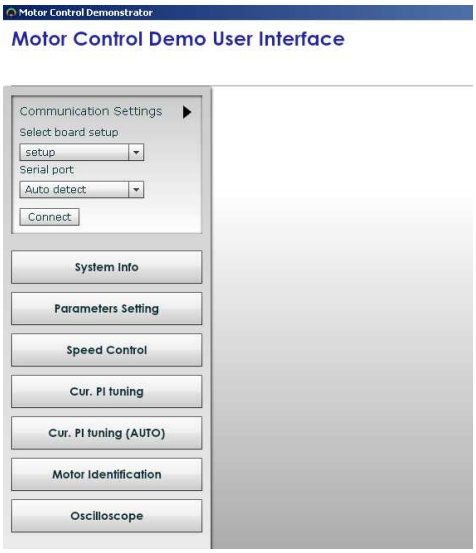


c) Let's connect the $24V_{DC}$ Power supply to the RX62T motor control reference kit:

d) Now, connect the USB cable to the PC and the Kit and connect the 24V to the kit and the motor to the kit:



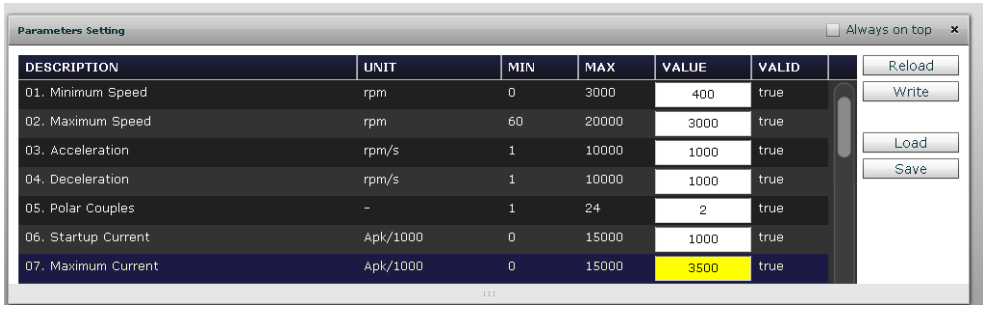
e) Launch the PC GU from the folder: “C:\Program Files\MCDEMO” launch: “MotorController.exe”



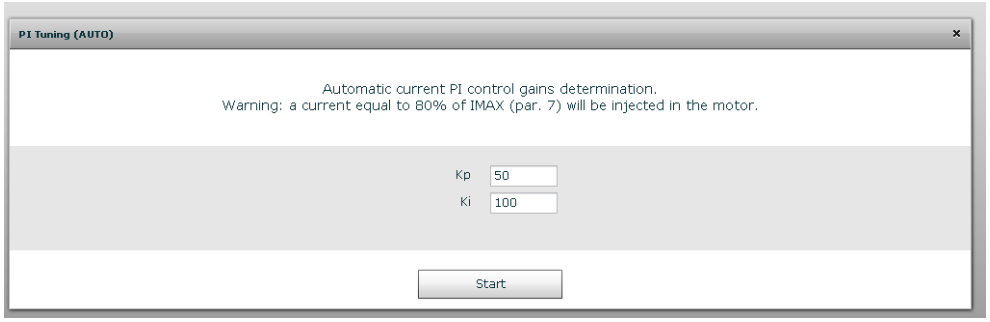
Click on the “setup” button and select “RX62T Kit” and select “Autodetect” and click on “Connect” to ensure the PC GUI is connected to the RX62T kit.

On the left hand side, the new buttons appears: “Cu. PI tuning”, “Cu. PI tuning (AUTO)”, “Motor Identification” and “Oscilloscope”.

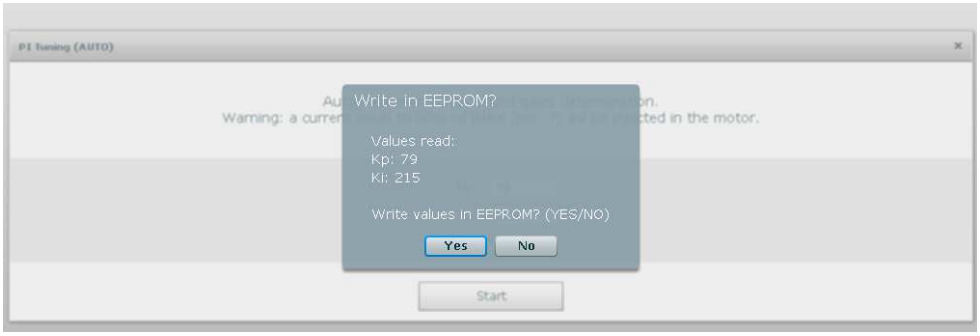
f) Set the **maximum current** (parameter n°07) as it will influence all the next steps: Click on “Parameters settings” Enter the value: 3500 (the unit is in mA) and click on “Write” to save the parameter into the EEPROM. And close the window


Parameters Setting
Always on top
DESCRIPTION UNIT MIN MAX VALUE VALID
01. Minimum Speed rpm 0 3000 400 true
02. Maximum Speed rpm 60 20000 3000 true
03. Acceleration rpm/s 1 10000 1000 true
04. Deceleration rpm/s 1 10000 1000 true
05. Polar Couples - 1 24 2 true
06. Startup Current Apk/1000 0 15000 1000 true
07. Maximum Current Apk/1000 0 15000 3500 true
Reload
Write
Load
Save

g) Click now on “Cu. PI tuning (AUTO)” button and press “start” to perform an automatic Current PI tuning.

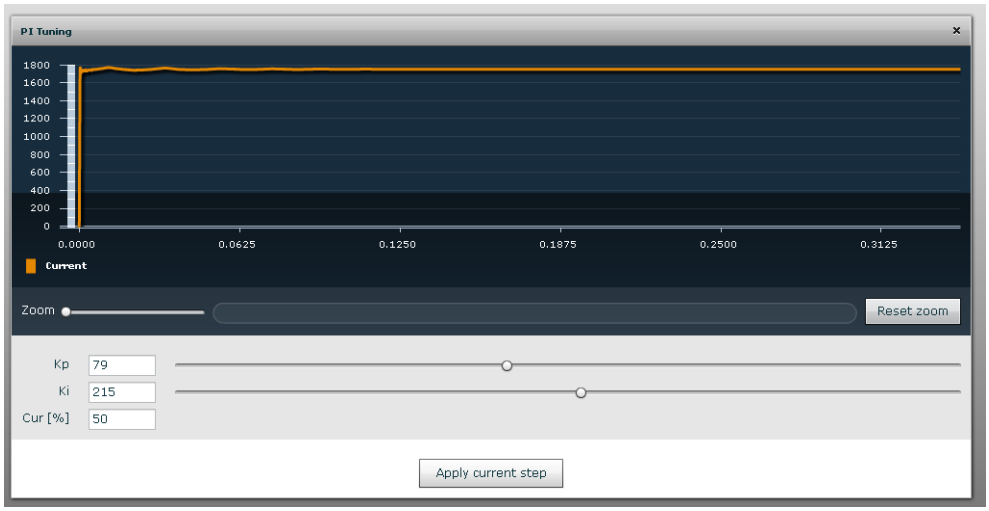

PI Tuning (AUTO)
Automatic current PI control gains determination.
Warning: a current equal to 80% of IMAX (par. 7) will be injected in the motor.
Kp 50
Ki 100
Start

And accept the results to be programed into the EEPROM as shown below.

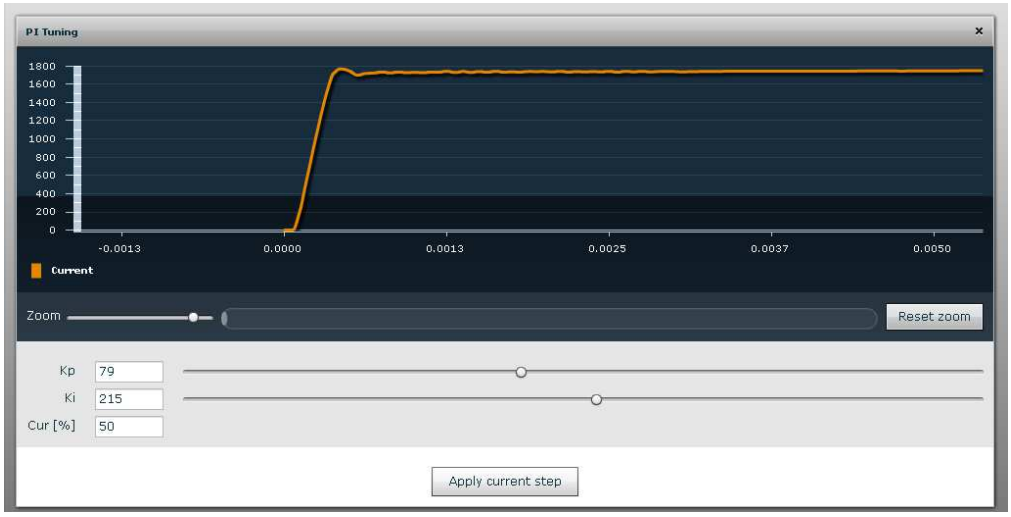


h) Now click on the button “Cu. PI tuning” to open the manual current PI tuning window and check the step answer by clicking on “Apply current step” button.

Depending on the motor, the parameters found by the automatic procedure can be too fast or too slow.

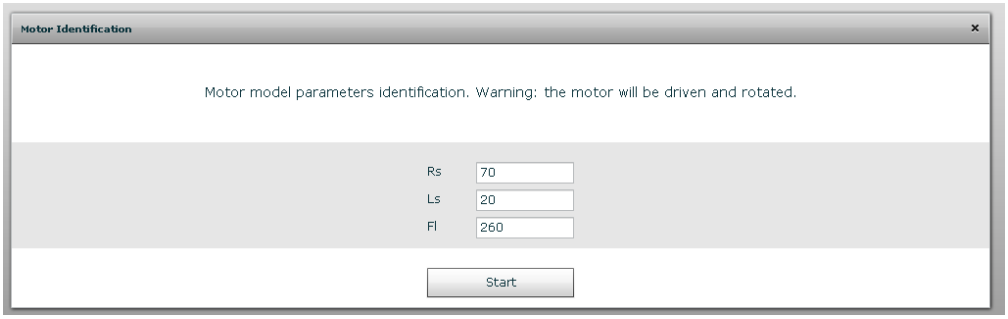


Please use the Zoom function to check the beginning of the step:

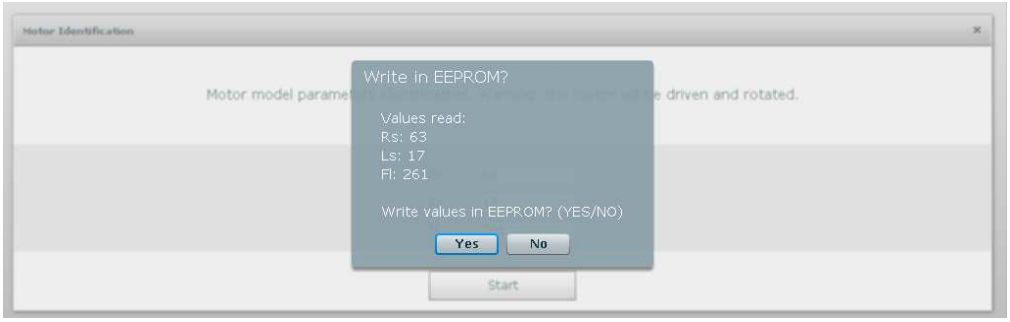


You can adjust manually the parameters to obtain an even better step response and also increase the step current level by increasing the percentage of “Cur. [%] to 90%. The default value is 50%.
Once it’s done, the window can be closed as the proportional and integral coefficients of the PI current are tuned.

i) Perform an auto-identification of the motor parameters by clicking on “Motor Identification” and click “start”:



And accept the results to store them into the EEPROM.

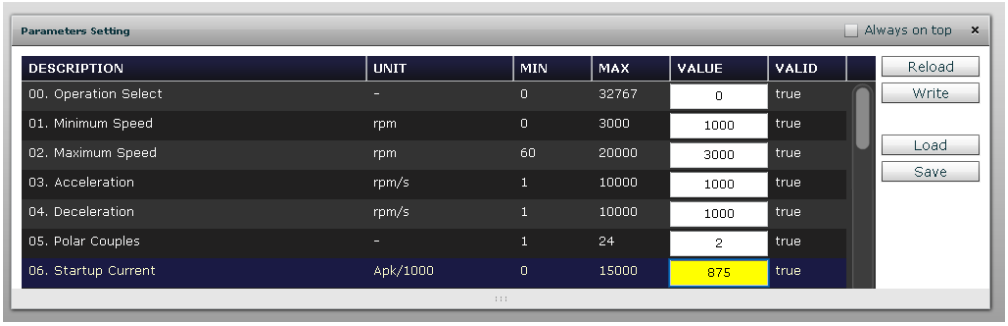


The stator resistance, the synchronous inductance and the Permanent Magnet flux have been measured and tuned.

j) Now please click on “parameters settings” and enter the number of pole pairs: 2 (parameter n°5) and enter a minimum speed or 1000 RPM (15Hz of a one pole pair motor).

Parameters Setting
Always on top
DESCRIPTION UNIT MIN MAX VALUE VALID
00. Operation Select - 0 32767 0 true
01. Minimum Speed rpm 0 3000 1000 true
02. Maximum Speed rpm 60 20000 3000 true
03. Acceleration rpm/s 1 10000 1000 true
04. Deceleration rpm/s 1 10000 1000 true
05. Polar Couples - 1 24 2 true
06. Startup Current Apk/1000 0 15000 1000 true
Reload
Write
Load
Save

k) Set a start-up current equal to 25% of the maximum current. In our case 25% of 3.5A is 0.875A. Please enter the value 875 into the parameter n°6 and click on the “write” button on the left.

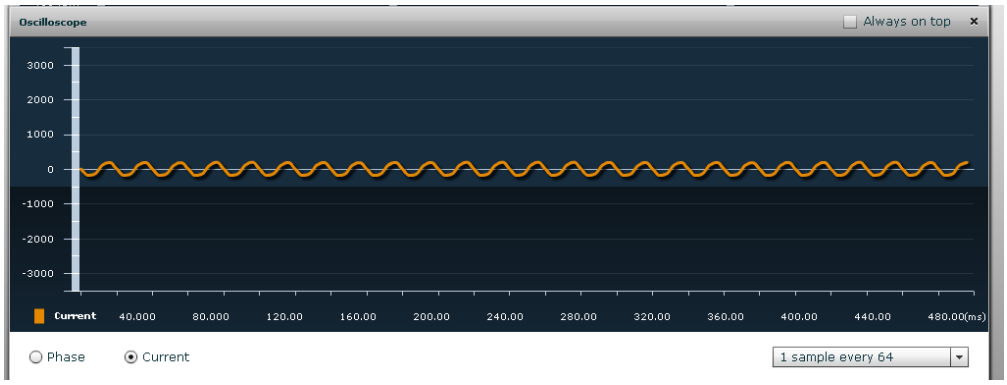

Parameters Setting
Always on top
DESCRIPTION UNIT MIN MAX VALUE VALID
00. Operation Select - 0 32767 0 true
01. Minimum Speed rpm 0 3000 1000 true
02. Maximum Speed rpm 60 20000 3000 true
03. Acceleration rpm/s 1 10000 1000 true
04. Deceleration rpm/s 1 10000 1000 true
05. Polar Couples - 1 24 2 true
06. Startup Current Apk/1000 0 15000 875 true
Reload
Write
Load
Save

Let’s close the window.

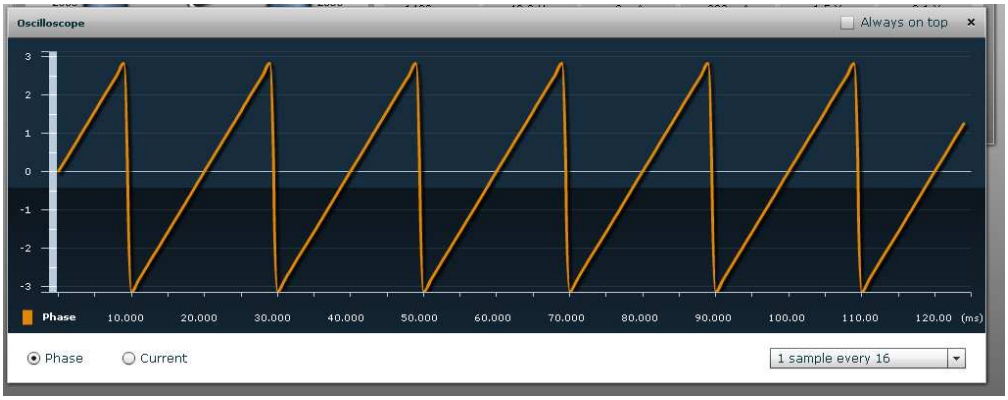
l) Please click on the button: “Speed Control”:

To start the motor, let’s enter a speed which is 1.5 times the minimum speed, in this case **1500 RPM**

Please click on the “Oscilloscope” button to see the motor waveforms with the current in Y-axis and the time in x-axis.



You can also display the phase by clicking on “Phase” selector:



For the oscilloscope window, use an opportune time scale: “1 sample every 1” should be used for extremely fast phenomena when running at very high speed.

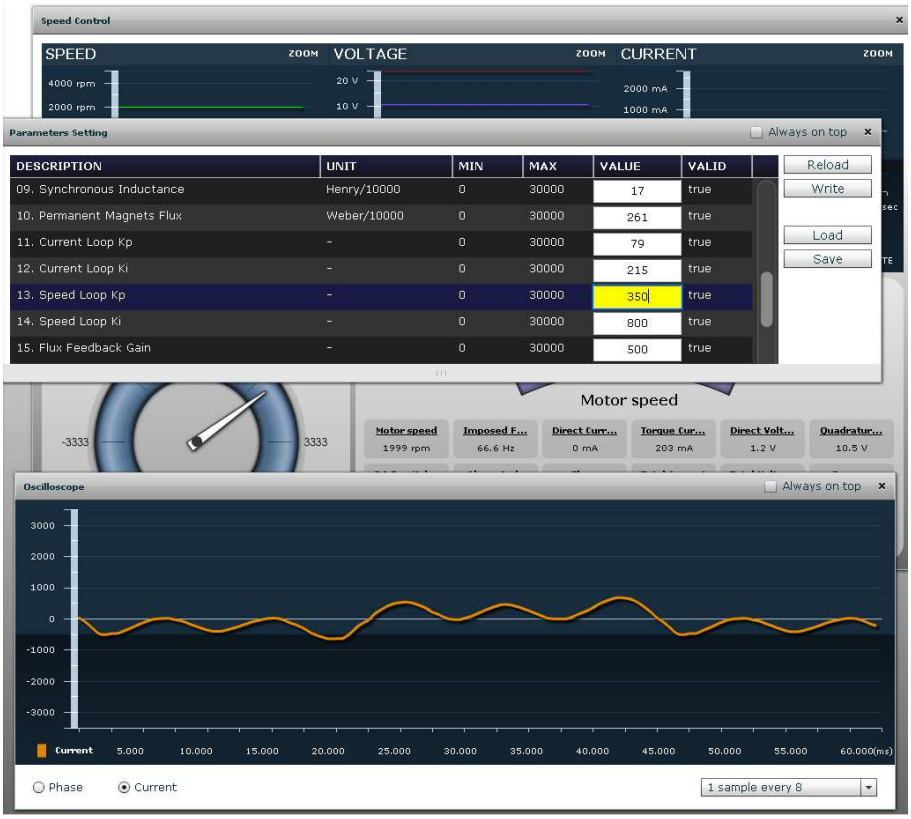
The setting “1 sample every 128” should be used for extremely low phenomena when running at very low speed. Let’s start with an intermediate value and adjust it in order to see some periods of the current or the phase.

When the motor is running, you can adjust the speed PI parameters.

Please follow the procedure: while running at a medium speed range: 2 times the minimum speed.
In our example, the speed is set to 2000 RPM

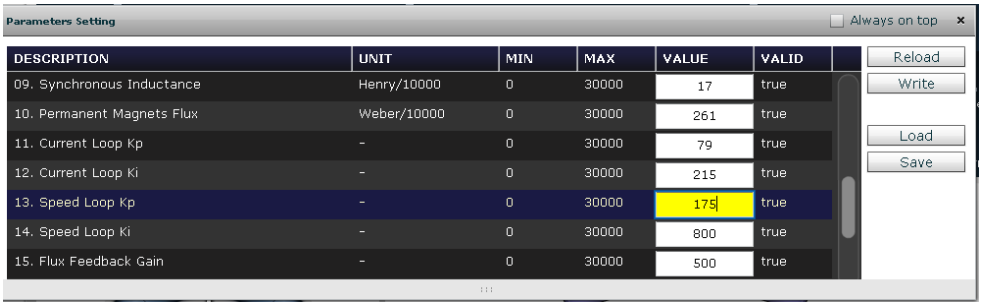
Start by increasing the Parameter n°13 (Kp) until the instability that can be display in the current or phase waveform window.

Add a step of “50” and click “write” to see the effect and keep on increasing it.



In our case, at 350 it started to be very unstable, but the motor is still running. Set the speed to “0”.

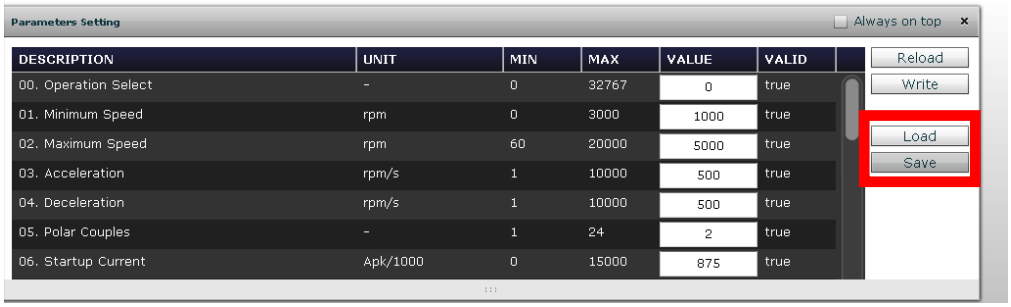
Then use half of the found value: 175 in our case, click on “write” and set the speed to 2000 RPM.



Do the same for the parameter n°14 which is the speed loop Ki parameter. Increase it until it becomes unstable.
In our case the critical value is reached at 2800 for Ki, so the value to be used is: 1400.

n) Test now all the speed ranges and different rotation.

o) Finally the parameters list can be saved in a file in .CSV format for further used and can also be uploaded later on:



Troubleshooting:
At the stage i) if the motor doesn't start or generate an alarm n°3, please set the speed to "0" to clear the alarm which indicates that the software lost the phase. One first test is to increase or decrease the start-up current and the minimum speed or the speed PI gains

When the motor is running, you can verify the number of pole pairs taking measurement of the effective speed, and comparing it with the imposed frequency: the number of pole pairs n is: n=freq*60/speed; if you change the number of pole pairs, remember to adjust also the minimum (and maximum) speed values.
Sometimes the no load start-up is easier if the inductance parameter is set to 0.

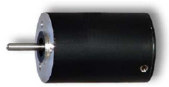
All the procedure is tuned to manage motors which maximum current is close to the inverter capability, which is around 6Arms for the external power stage (shunt=0.05Ohm) and 3Arms for the internal power stage (shunt=0.1Ohm); if you try to use it for very different motors, the results will be influenced by the losses in current reading resolution.

Another possible trick when the things are very difficult, is trying to increase the flux feedback gain; sometimes I used 500 instead of 100.

20. List of motors tuned automatically using the PC GUI

Please find below a short list of AC Brushless motors tuned automatically using the auto-tuning procedure described above.

For each motor a specific text file is available to be loaded onto the PC GUI.

						
Part-name	ECI 24.42	BD35F	BLDC15P06	BLDC58-50L	MB057GA240	FL28BL38
Motor maker	EBM-PAPST	Danfoss Compressor	PMDM Minebea	Premotec	Speeder Motion	Fulling Motor
Voltage	24V	24V	12V	24V	50V	24V
Maximum Speed in RPM	3000	3500	12000	12000	5000	13000
Polar Couples	2	2	2	2	2	2
Startup Current in Apk/1000	1000	1000	1000	1000	875	200
Maximum Current Apk/1000	6000	3000	3000	3000	3500	400
Stator Resistance in Ohm/100	38	125	45	30	63	220
Synchronous inductance in Henry/10000	6	12	5	3	17	25
Permanent Magnets Flux in Weber/10000	178	333	42	52	264	30
Current PI - Prop. Coefficient: Kp	18	73	4	10	80	30
Current PI -Integ. Coefficient: Ki	40	80	10	20	215	20
Speed Loop Kp	30	30	50	40	175	120
Speed Loop Ki	400	400	100	300	1400	50
Flux Feedback Gain	400	100	400	400	100	500
Filename in csv format	EBMPAPST_ECI_24.42_24V_3000RPM	DANFOSS_BD35F_24V_3500RPM	MINEBEA_BLDC15_12V_12000RPM	PREMOTEC_BLDC58_24V_12000RPM	SPEEDERMOTION_MB057GA240_5000RPM	FULLING_FL28BL38_13000RPM

21. List of variables used in the file name: “motorcontrol.c”

The file called “motorcontrol.c” includes the motor control algorithm routines. Please find below the description of the variables used in this file.

Label(s)	Type	Description	Unit
ium_off, ivm_off, iwm_off	float	A/D conversion offsets of measured u, v, w phase currents; the value is around 2048, that corresponds to one half of the A/D converter supply voltage (5Vdc) (12bit A/D).	
vol_ref	float	A/D conversion result of the reading of the reference voltage (4.25V); used for compensate the effects of the power supply variations in the A/D conversions; the ideal value is 870 (10bit A/D), if the A/D converter supply voltage is exactly 5V.	
kadi, kadv	float	Current and voltage conversion constants; they are corrected on the grounds of vol_ref, and they are used to convert the A/D results in the used measurement units; multiplying the A/D result by the conversion constant, the current (voltage) in Ampere (Volt) is obtained (ex.: iu=kadi*(iuad-ium_off))	
r_sta	float	Stator resistance	ohm
l_sync	float	Synchronous inductance	henry
c_poli	float	Number of polar couples	
krpmocp, ukrpmocp	float	Conversion constant between mechanical speed and electrical speed, and its reciprocal (ukrpmocp=1/krpmocp).	(rad/s)/rpm, rpm/(rad/s)
vstart	float	Startup voltage in single shunt operation; during startup, first a voltage ramp at zero speed is performed, then a voltage and speed ramp; vstart is the actual value.	volt
vs_off	float	Offset startup voltage in single shunt operation; vs_off is the total starting value (total voltage at zero speed).	volt
vs_inc	float	It is the quantity added at every zero speed ramp step to obtain vs_off.	volt
vs_del	float	Total voltage quantity added during startup in single shunt operation; added to vs_off, it gives the voltage applied when the voltage and speed ramp is finished.	volt
vs_dela	float	Voltage quantity added at every voltage and speed ramp step during startup in single shunt operation.	volt
istart	float	Startup current in three shunts operation; during startup, first a current ramp at zero speed is imposed, then a speed ramp with constant current (istart).	ampere
is_inc	float	Startup current increment at every step.	ampere

Label(s)	Type	Description	Unit
omegae_s	float	Electrical speed during startup (instant value)	rad/s
delta_om	float	Speed quantity added at every step during startup ramp.	rad/s
om_chg	float	Speed to reach during the startup; when this speed is reached, the startup ramp ends.	rad/s
startup_phase	float	Electrical phase during startup.	rad
delta_ph	float	Phase variation at every step during startup.	rad
vdx, vqx, vdxf, vqxf	float	D and q axis voltages (instant and filtered) during startup.	volt
idx, iqx, idxf, iqxf	float	D and q axis currents (instant and filtered) during startup.	ampere
SystemPhase	float	Imposed electrical phase.	rad
Phase_est	float	Estimated electrical phase.	rad
vbus, vbusf	float	DC link voltage, instant value and filtered one.	volt
xvbf	float	DC link voltage, min. ripple value, used for voltage clamping.	volt
vfmax	float	Maximum allowed phase voltage (star).	volt
vdmax, vdmax	float	Maximum d and q axis allowed voltages.	
i_max, iq_max	float	Max. allowed total current, maximum allowed q axis current.	ampere
vdc, vqc, vdcf, vqcf	float	D and q axis imposed voltages, instant and filtered values.	volt
vac, vbc	float	Alpha and beta axis voltages.	volt
vuc, vvc, vwc	float	Phase voltages (star).	volt
old_va, old_vb	float	Previous step alpha and beta axis voltages.	volt
ium, ivm, iwm	float	Measured phase currents.	ampere
iam, ibm	float	Measured alpha and beta axis currents.	ampere
idm, iqm, idmf, iqmf	float	Measured d and q axis currents (instant and filtered values).	ampere
idr, iqr	float	D and q axis reference currents.	ampere
id_dec	float	After the startup, the d axis current residual is decreased till zero; id_dec is the variation at every step.	ampere
idint, iqint	float	Current PI integral memories.	volt
idimem, iqimem	float	Current PI integral memories; this values are used in single shunt operation to stop the integral action when the current reading is not possible.	volt

Label(s)	Type	Description	Unit
errint	float	Speed PI integral memory	ampere
kp_cur, ki_cur	float	Proportional and integral constant in current PI controllers.	volt/ampere
kp_vel, ki_vel	float	Proportional and integral constant in speed PI controller.	ampere/(rad/s)
freq	float	Electrical frequency.	hertz
mec_rpm	float	Mechanical speed.	rpm
rpmrif_x	float	Reference speed (speed ramp input value).	rpm
rpmrif_y	float	Reference speed (speed ramp output value).	rpm
rpmrif_abs	float	Absolute value of rpmrif_y.	rpm
r_acc, r_dec	float	Acceleration ramp, deceleration ramp.	rpm/s
rpm_min, rpm_max	float	Minimum and maximum allowed speed.	rpm
min_speed, max_speed	float	Minimum and maximum electrical speed.	rad/s
min_speed_trip, max_speed_trip	float	Minimum and maximum electrical speed (values used for estimation error detection).	rad/s
Speed_est	float	Estimated electrical speed.	rad/s
omrif, f_omrif	float	Reference electrical speed (instant and filtered values).	rad/s
omegae, omegae_f, omf	float	Imposed electrical speed (instant and filtered values).	rad/s
maxerr	float	Maximum electrical speed error.	rad/s
vbus_ulpkt_slow, vbus_ulpkt_fast	float	One divided by K, where K is the time constant of the vbus low-pass filter (slow and fast).	1/s
speedref_ulpkt	float	One divided by K, where K is the time constant of the speed reference low-pass filter.	1/s
startup_ulpkt	float	One divided by K, where K is the time constant of the startup low-pass filter.	1/s
off_ulpkt	float	One divided by K, where K is the time constant of the current offsets low-pass filter.	1/s
vr_ulpkt	float	One divided by K, where K is the time constant of the board reference voltage low-pass filter.	1/s
duty_u, duty_v, duty_w	signed short	PWM duty cycles for the three phases.	MTU pulses

Label(s)	Type	Description	Unit
vbus_ad	signed short	A/D conversion result of the DC link voltage reading.	
iss_off	signed short	A/D conversion offsets of measured single shunt current; the value is around 2048, that corresponds to one half of the A/D converter supply voltage (5Vdc) (12bit A/D).	
iaad, ibad	signed short	A/D conversion result of the first and the second single shunt current reading.	
deadtim	unsigned short	Dead-time.	MTU pulses
semiper	unsigned short	PWM half period.	MTU pulses
semiperdead	unsigned short	PWM half period plus dead-time.	MTU pulses
cr_ss	unsigned short	Status variable for single shunt current reading.	
trip_cnt	unsigned short	Counter for estimation error detection.	
startup_cnt	unsigned short	Counter for startup.	
startup_val	unsigned short	Startup time.	N° of sampling periods
stp_tim	unsigned short	Startup time.	ms
XXXXXX_ep	unsigned short	Many variables with suffix “_ep”: they are copies of various parameters, used for EEPROM management.	
enc_ind	unsigned short	Index in encoder filter table.	
enc_sam	unsigned short	Encoder sample.	
enc_ang	unsigned short	Encoder angular position.	2PI is 65536
mec_ang	float	Mechanical position.	rad
ele_ang	float	Electrical angular position.	rad
off_ang	float	Electrical position offset.	rad

Label(s)	Type	Description	Unit
tele_ang	float	Corrected electrical position.	rad
om_mec	float	Mechanical angular speed.	rad/s
om_eme	float	Electro-mechanical angular speed.	rad/s
enc_buf[]	float	Encoder filter buffer.	rad

Revision History

		Description	
Rev.	**Date**	**Page**	**Summary**
1.00	Jan 15, 2014		First Edition

General Precautions in the Handling of MPU/MCU Products

The following usage notes are applicable to all MPU/MCU products from Renesas. For detailed usage notes on the products covered by this document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

1. Handling of Unused Pins
   Handle unused pins in accord with the directions given under Handling of Unused Pins in the manual.
   — The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible. Unused pins should be handled as described under Handling of Unused Pins in the manual.
2. Processing at Power-on
   The state of the product is undefined at the moment when power is supplied.
   — The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the moment when power is supplied.
   In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the moment when power is supplied until the reset process is completed.
   In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the moment when power is supplied until the power reaches the level at which resetting has been specified.
3. Prohibition of Access to Reserved Addresses
   Access to reserved addresses is prohibited.
   — The reserved addresses are provided for the possible future expansion of functions. Do not access these addresses; the correct operation of LSI is not guaranteed if they are accessed.
4. Clock Signals
   After applying a reset, only release the reset line after the operating clock signal has become stable. When switching the clock signal during program execution, wait until the target clock signal has stabilized.
   — When the clock signal is generated with an external resonator (or from an external oscillator) during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Moreover, when switching to a clock signal produced with an external resonator (or by an external oscillator) while program execution is in progress, wait until the target clock signal is stable.
5. Differences between Products
   Before changing from one product to another, i.e. to a product with a different type number, confirm that the change will not lead to problems.
   — The characteristics of an MPU or MCU in the same group but having a different part number may differ in terms of the internal memory capacity, layout pattern, and other factors, which can affect the ranges of electrical characteristics, such as characteristic values, operating margins, immunity to noise, and amount of radiated noise. When changing to a product with a different part number, implement a system-evaluation test for the given product.

Notice

1. Descriptions of circuits, software and other related information in this document are provided only to illustrate the operation of semiconductor products and application examples. You are fully responsible for the incorporation of these circuits, software, and information in the design of your equipment. Renesas Electronics assumes no responsibility for any losses incurred by you or third parties arising from the use of these circuits, software, or information.
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5. Renesas Electronics products are classified according to the following two quality grades: "Standard" and "High Quality". The recommended applications for each Renesas Electronics product depends on the product's quality grade, as indicated below.
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SALES OFFICES Renesas Electronics Corporation http://www.renesas.com

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Renesas Electronics America Inc.
2880 Scott Boulevard Santa Clara, CA 95050-2554, U.S.A.
Tel: +1-408-588-6000, Fax: +1-408-588-6130

Renesas Electronics Canada Limited
1101 Nicholson Road, Newmarket, Ontario L3Y 9C3, Canada
Tel: +1-905-898-5441, Fax: +1-905-898-3220

Renesas Electronics Europe Limited
Dukes Meadow, Millboard Road, Bourne End, Buckinghamshire, SL8 5FH, U.K
Tel: +44-1628-651-700, Fax: +44-1628-651-804

Renesas Electronics Europe GmbH
Arcadiastrasse 10, 40472 Düsseldorf, Germany
Tel: +49-211-65030, Fax: +49-211-6503-1327

Renesas Electronics (China) Co., Ltd.
7th Floor, Quantum Plaza, No.27 ZhiChunLu Haidian District, Beijing 100083, P.R.China
Tel: +86-10-8235-1155, Fax: +86-10-8235-7679

Renesas Electronics (Shanghai) Co., Ltd.
Unit 204, 205, AZIA Center, No.1233 Lujiazui Ring Rd., Pudong District, Shanghai 200120, China
Tel: +86-21-5877-1818, Fax: +86-21-6887-7858 / -7898

Renesas Electronics Hong Kong Limited
Unit 1601-1613, 16/F., Tower 2, Grand Century Place, 193 Prince Edward Road West, Mongkok, Kowloon, Hong Kong
Tel: +852-2886-9318, Fax: +852 2886-9022/9044

Renesas Electronics Taiwan Co., Ltd.
13F, No. 363, Fu Shing North Road, Taipei, Taiwan
Tel: +886-2-8175-9600, Fax: +886 2-8175-9670

Renesas Electronics Singapore Pte. Ltd.
80 Bendemeer Road, Unit #06-02 Hyflux Innovation Centre Singapore 339949
Tel: +65-6213-0200, Fax: +65-6213-0300

Renesas Electronics Malaysia Sdn.Bhd.
Unit 906, Block B, Menara Amcorp, Amcorp Trade Centre, No. 18, Jln Persiaran Barat, 46050 Petaling Jaya, Selangor Darul Ehsan, Malaysia
Tel: +60-3-7955-9390, Fax: +60-3-7955-9510

Renesas Electronics Korea Co., Ltd.
11F., Samik Lavied' or Bldg., 720-2 Yeoksam-Dong, Kangnam-Ku, Seoul 135-080, Korea
Tel: +82-2-558-3737, Fax: +82-2-558-5141

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